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THE DYNAMICS OF DEFENCE PLANNING
Or
"Are We Preparing for the Wrong Sort of War?"

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Eric John Risness was educated at Stratford Grammar School, London, and Corpus Christi College, Cambridge. After taking a Ph.D. degree in Nuclear Physics ("A Resonant Cavity Electron Accelerator") he joined the R.N.S.S. in 1954 at ARL, Teddington. He worked on the application of digital techniques to passive sonar processing problems until 1961, when he moved to AUWE to work on the application of digital computer techniques to active sonar detection and tracking. In 1967 he took over the Sonar Techniques Research and A/S Training Division. After a year at the Imperial Defence College he returned to AUWE in charge of the Underwater Weapons Research Division.

Abstract

On historical and other grounds, it is suggested that wars can often be expected to last several years, and to be preceded by periods of rising tension. Consequently, in an era of reduction in Defence expenditure (itself due partly to a general lowering of world tension), it is not necessarily appropriate to use all the available money solely to maximise the effectiveness of the standing Armed Forces. Instead it may be desirable to allocate some money to maximise the effective build up of possible future Forces, even at the expense of current strength. Some implications of this policy are discussed.

Introduction

It is difficult sometimes for those of us, whether military or civilian, who have been involved in Defence over the past 10 years or more to realise just how dramatically the whole approach to Defence planning has changed during this period. Quite apart from changes in the world situation—this country's overseas commitments have reduced enormously during the decade—there have been two fundamental, related innovations in planning for Defence. One, associated in most people's mind with the Polaris programme, is the development of programme management techniques—PERT charts, cost control, and so on. The other, associated with the era of Robert McNamara at the U.S. Department of Defence, is the application of cost-effectiveness analysis to Defence decision-making. Both of these changes reflect the desire to apply good business techniques to planning in an era of increasing financial stringency.

This article was written while the author was at the Imperial Defence College.

We have now reached the situation in this country—and it is very similar in many other Western countries—where the Government allocates a fixed sum of money for Defence (about £2,000 million per annum), the Defence planners aim for the most cost-effective expenditure of that money, and then see what sort of Defence posture the country can achieve. With a known and more or less fixed rate of expenditure laid down for the indefinite future it is possible to be relatively precise about the size and shape of the Armed Forces, and to make detailed plans about equipment, logistic support, training requirements and so on. These detailed plans can be optimised to minimise costs given the overall Defence picture. For example the R.A.F. have recently reviewed their flying training programme and have been able to achieve very significant economies by tailoring their programme to match the current number of trained fliers required annually by the R.A.F.

Defence is thus being run as a business, a commercial enterprise with a constant turnover and with all facets of the enterprise dovetailed together to make the most effective use of capital investment and annual income. This has many advantages, but, as is well known, has one crucial disadvantage, namely that in the last resort the overall "effectiveness" of defence cannot be measured except in time of war. All attempts to optimise defence expenditure depend on the definition of some hypothetical situation or scenario in which the Armed Forces could become involved, and credible scenarios are becoming more and more difficult to specify.

Predictions About Future Conflict

The purpose of this article is not to consider this problem in general, but to focus attention on one particular aspect of Defence planning which is in danger of being forgotten entirely in this environment of cost effectiveness and business management. This aspect derives from the fact that Defence planning, and indeed all business planning, is not static but needs to change dynamically as future prospects change. In all business planning which depends on forecasts of the future, plans may have to be changed as time goes on because future trends can be estimated more accurately. At the present (end 1970) it may be desirable to predict, for example, the market for cars in 1975. This prediction could be revised at the end of each subsequent year, and one would expect the prediction to become successively more accurate until the end of 1975 is reached, when the 'prediction' becomes a fact which can be measured. This pattern is characteristic of most business planning; a pattern of prediction with no expected bias but an expected variance which decreases towards zero as the date approaches to which the prediction refers.

In Defence the situation is different. The analogue to a business prediction about the future market is a Defence prediction about the future state of war, the most important single prediction being the likelihood that the country will be at war at some date in the future. But an estimate of this likelihood does not necessarily show the pattern characteristic of commercial predictions (no bias and a decreasing variance with time), but can under many circumstances show a steady downward trend as time goes on. To illustrate this point, let us take a highly idealised example. Assume that a country gets involved in a major war once every 30 years on average and that each war lasts three years on average. Assume also that the start of a war is entirely unpredictable, and that the country is currently at peace. The chance of the country being at war tomorrow is roughly 1 in 10,000, but because a war is assumed to last three years, the chance of being at war rises by 1 part in 10,000 for each successive day, and the likelihood of being at war in three years' time has reached 1 in 10.

Thus, viewed from the end of 1970 the chance of being at war at the end of 1972 is 1 in 15, but at the end of 1971 if the country is still at peace the chance of being at war at the end of 1972 will have dropped by a factor of 2, to 1 in 30. To see the implication of this, let us carry this artificial example a stage further. Let us assume that at the end of 1970 we have to make some planning decision involving Defence expenditure (perhaps in competition with other expenditure) and that this decision depends on our current assessment of the likelihood of war two years ahead. Let us also assume that this decision will be reviewed again at the end of 1971, and although it cannot be entirely reversed then—some of the money will already have been spent, for one thing—it can be modified in the light of expectation at the time about the situation at the end of 1972. Now if the country is still at peace the expectation of war at end-1972 has changed, and it may therefore be appropriate to modify the previous decision, perhaps to slow down the project or even to cancel it. (Of course if the converse happens and the country goes to war during 1971 one would expect all relevant plans to be modified in the other direction, to increase the war effort.)

Thus in terms of the " cost effectiveness " or " cost-benefit " concept of planning, it can be seen that, whereas in most business enterprises one's estimate of the expected benefit of any plan (*e.g.* the market for cars in 1975) may fluctuate as time goes on, it is not normally expected to show any systematic trend. With Defence, however, assessments of benefit or effectiveness based on the likelihood of actual war can be expected to show a trend downwards if peace continues, and of course sharply upwards if war actually breaks out. This downward trend in peacetime means that " cost-effectiveness " may have to be reassessed purely due to the passage of time, and that plans and decisions already made about Defence expenditure can legitimately be modified on the basis that another year has passed without war, quite apart from other reasons such as rising costs or changing technology.

Likely Duration of War

In the idealised situation just discussed, it is important to note the part played by the assumed average duration of a war. The argument only works when the period over which predictions are to be made, and the fraction of this period in which modification can be considered, are both comparable with the expected duration of the war. If a future war was expected to last three days rather than three years the whole argument would be of negligible interest.

What then can be said about the likely duration of future wars? Let us begin by considering the evidence from recent wars. Wood[1] has analysed all military conflicts which have occurred in the world since 1900, from the largest wars down to small scale coups d'etat and other national events which have involved actual fighting by the military. (Clearly there is some difficulty in drawing a clear-cut lower limit.) He has shown that since 1939 there have been 83 distinguishable conflicts, of which 40 have lasted three years or longer. Of the 15 conflicts in which the United Kingdom was involved since that date, 11 have lasted three years or longer.

One must of course be extremely careful in extrapolating from the past into the future. For one thing, many of the conflicts in which the United Kingdom was involved arose in the last stages of British colonial rule or followed in the aftermath of that period (*e.g.* the Malaysian/Indonesian confrontation), and it cannot be assumed that Britain will be involved in such conflicts in the future, at any rate to the same extent.

Secondly, the most dangerous and frightening conflict facing mankind is all-out nuclear war which has not, of course, been experienced before, and which is likely to last only a few days—though it may be followed by a drawn-out conventional war (the "broken back " phase, as it is euphemistically called by those who think about the unthinkable). A similar situation is postulated for all-out war in Europe between NATO and the Warsaw Pact countries. The current expectation is that NATO, faced with much stronger conventional forces from the East, could defend for only a limited number of days before threatening a strategic nuclear exchange.

But, just because nuclear war is so horrifying, one must not therefore be misled into over emphasising such a war to the exclusion of all else. In fact it is clear to all that the threat of nuclear war has kept the peace between the super-powers, and that although all-out war in Europe leading to nuclear war may be the most *dangerous* scenario facing the West it is not the most *likely*. The conventional wars in which one or both super-powers have directly or indirectly intervened since 1945 (Korea, Vietnam, the Arab-Israel conflict, etc.) have been marked by a desire not to let the war get out of hand because of the dangers of ' escalation ' to nuclear war, and this of itself has helped to prolong rather than curtail the war in most cases.

Thus in spite of the exception posed by nuclear war it is reasonable to suppose that future conflicts in which the West in general, and the United Kingdom in particular, may become involved are likely to last several years on average.

Changes in International Tension

So far we have assumed that although a war is likely to last for several years its date of onset is entirely unpredictable. In practice wars are often preceded by a period in which tensions rise between two countries or groups of countries, so that the likelihood that war will break out becomes more and more apparent even though the precise date and form of the war remains unknown. World War II provided a classic example, with the probability of a war between Britain, France and Germany rising steadily during the second half of the 1930's. It is more difficult to make useful quantitative statements about the likely duration of this "build-up" period than about the likely duration of the subsequent war, but from the general pattern of conflict since World War II it could be argued that tension between individual countries builds up before a war (or relaxes for that matter, at other times) over a period of some years. Indeed between large power groups such as NATO and the Warsaw Pact countries the variations of tension might be slow enough to be measured in decades rather than years.

It is of course easy to be wise after the event, and not many wars have been unambiguously predicted several years ahead. Nevertheless it does seem rational to suggest that international tensions throughout the world have broadly been reducing in the last two decades, and that medium to large scale war (even including nuclear war) is unlikely without some prior measurable increase in world tension spread over a period of years rather than days.

The Armed Forces of a country of course play a part in *deterring* war, as well as in fighting when it actually breaks out. The general effect of this deterrent role will be referred to later. For the moment it should be noted that in so far as the Armed Forces have had a deterrent role in modifying the course of rising tension and subsequent war, this effect is included in deductions drawn from recent history. But of course the degree to which the Armed Forces have deterred wars from starting at all (nuclear war is the obvious, but not the only example) cannot, almost by definition, be determined, and this must be borne in mind as a limitation in all the subsequent discussion.

A "Five Year Plan" for Defence

In view of the postulate that, instead of being faced with an unpredictable, short-duration war at any time we are more likely to become involved in a drawn-out war preceded by a period of rising tension, are we right to plan our defence solely on the basis of maximising the effectiveness of standing Armed Forces constrained by a fixed budget?

Let us, to clarify ideas, consider a possible alternative, deliberately exaggerated in places. Suppose that, instead of planning a fixed sum of £2,000 million per annum on defence and trying to build a balanced Army, Navy and Air Force with a maximum ratio of "teeth" to "tail", the Defence vote was cut to £1,500 millions with the following aims:—

(a) To spend the major part of this sum (say £1,000 million) on maximising the readiness of the standing Armed Forces to meet immediate, unpredictable threats, including in particular the nuclear deterrent and all-out war in Europe.

(b) To spend the rest of the money as appropriate on the assumption that, if world tension started to rise, annual Defence expenditure could be increased to a level of £3,000 million in five years time, and the current money should be spent to help maximise the effectiveness of the Armed Forces at that future date.

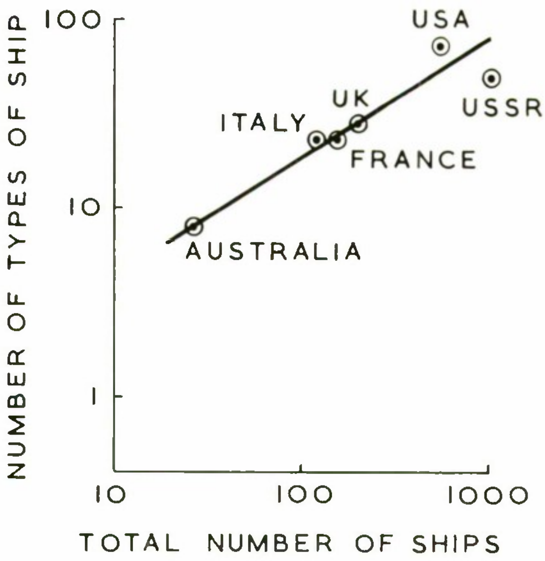
Thus as seen from the end of 1970 part of the money for 1971 would be spent on maximising the effectiveness of the standing Armed Forces, and the rest on whatever "long lead" items are necessary to maximise the effectiveness of a larger Armed Force (roughly three times as large in cost terms) in 1975. If during 1971 the general state of tension in the world does not change for the worse, at least as far as the United Kingdom is concerned, then the budget for 1972 would be developed on the same basis but now maximising preparedness for a rise in expenditure and force levels by 1976.

Leaving aside for the moment the absolute levels of expenditure suggested, how does the suggestion to spend a proportion of the money on maximising effectiveness in five years time affect the *balance* of defensive expenditure? It clearly means that those items of defence spending which would be needed by the expanded force in five years time, and which take more than five years to come to fruition, must be financed now. For example, if the Navy needed two dockyards for the expanded fleet, and only one for the current fleet, and if a dockyard took more than five years to establish, then a second dockyard should be kept available even though the standing fleet does not require it.

Broadly speaking it is clear that manpower for the Services could be expanded within a five year time scale if war tension started to rise, but the main trouble would be in the area of equipment and logistic support. Until World War II a five-year lead time would have been sufficient to raise the level of both men and equipment and the problems we are now discussing would not have arisen. The reason it is now of importance is that the time span required for the design, development and production of equipment is now considerably longer than five years. Even the production alone of large-scale equipment (ships, for example) may take longer than this limit.

Clearly then money should be spent on the production and maintenance of extra dockyards, airfields and ships in case they are required, and on maintaining the *capacity* to produce aircraft, tanks and many other weapon systems for which complex production facilities are needed. Also although the majority of men required may be obtainable and trainable within the five-year period, the *capacity* to expand training would be needed, and the control and organisation to manage the larger force, plus officers and skilled men required, would have to be allowed for.

A larger force not only needs a larger *quantity* of weapons and other equipment; it also in general needs a larger *variety*. Or, to look at it the other way round, if the size of a force has to be cut then not only should the number of systems be reduced, but it makes sense to reduce at the same time the number of varieties. (In an era of reduction such as we are in now, this is one reason for the increased emphasis on multi-role or general purpose systems, the other being a general rise in development costs). It follows that if a force is to be planned for possible expansion to, say, three times its present figure, then it may need to plan for further types of weapon systems. We may get some idea of the order of magnitude involved by taking a specific example of a class of system in use throughout the world in Armed Forces of different sizes, and see how the number of varities of system correlate with the size of the force. A convenient class of system to take is ships and submarines, where data is readily available[2]. The diagram shows the number of different types of ships and submarines plotted against the total number of such vessels in the U.S., U.S.S.R., U.K., French, Italian and Australian Navies. All fighting ships currently in service



are included, but support, training, and small coastal craft are omitted. It can be seen that there is a common overall trend between number of ships and number of types of ship. For a Navy of a few hundred ships (such as the Royal Navy), an increase in size by a factor of three is accompanied by an increase in types by a factor of more than two. In fact the United States, with about 500 ships of about 70 types, and the United Kingdom, with about 200 ships of about 28 types, both average only about seven ships of each type.

There is of course room for a lot of argument about these figures. No one would pretend that the proportion of ships of different types is optimum in any Navy; many of them were designed and built 20 or more years ago. Furthermore, with the increasing costs of producing new designs, most people would contend that the Royal Navy, and many other Navies, have too many different types of ship and too few ships of each type. (In this context it is noteworthy that the U.S.S.R. appears to have an average of about 18 ships of each type—over twice the U.S. figure. The figures for the U.S.S.R. may well be biassed, however, both by over estimating the number of ships of each type currently in service, and also by underestimating the number of distinguishable types). Nevertheless it would be reasonable to consider that, if one wanted to expand the Navy by a factor of three in an optimum way, then one ought to increase the number of types of ship at the same time by say 50%.

Similar arguments could no doubt be advanced for other equipment (aircraft, missile systems, radars, etc.).

Hence if one is to spend a proportion of the Defence budget in "long-lead" work against the contingency that the Services may have to expand markedly in say five years time, then money should be spent on the development of more varieties of equipment than are strictly needed by the minimal standing force. This could result in re-equipping the standard force more frequently than would otherwise be necessary. Alternatively some systems would be developed up to a certain point, then "put on the shelf" and finally abandoned if they are not needed.

We are, of course, unfortunately well used to the idea of developing new equipments and then abandoning them before they are brought into service. Such affairs as the TSR-2 cancellation have caused outcry against the waste of public money, charges of Government vacillation, and a lowering of morale in the Services and in industry. As a result we now have a horror of abandoning any project once it has started. The idea that it may be *good* planning to start to develop something and then, if the world situation does not deteriorate, to discontinue it some years later is rather difficult to swallow in this climate.

Fluctuation in Tension and in Defence Effort

The doubling of annual defence expenditure within a five-year interval implies a growth rate of 30% per year. Instead of putting an arbitrary five year limit on this process one can consider annual defence expenditure to be a variable which could go up or down according to current estimates of world tension but which had a practical upper limit on its growth of around 30% per year (at the time of Korea (1950 - 52) U.S. military expenditure trebled in three years; West German expenditure doubled between 1958 and 1962, and East German expenditure doubled between 1965 and 1968). Looked at this way it can be seen that if programmes which take five years to come to fruition should be planned for a maximum force twice present size then those which take 10 years should be planned for four times present size; and so on. Thus in the sequence research—development—design—production there ought to be a continuous graduation of effort, with relatively more going into the early stages, and less into the later stages, than would be needed if all research and development were to be necessarily carried through to production. Furthermore the level of effort in the earlier, long lead-time items ought to be less dependent on short time fluctuations in tension and expenditure than the later items.

Fluctuation in tension and hence in defence expenditure also means that effort has to be switched from civil to military requirements and back again. This implies that civil and military activities must not be sealed off from each other in separate compartments. Thus, for example, the case for carrying out the development and design of weapon systems in industry rather than in Government Establishments is strengthened (over and above all the other reasons for it). Where research and early development is carried out in Government Establishments, then such Establishments should also have some civil work on their plate if possible in order to maximise this flexibility (even though, as has already been argued, the fluctuation of the most forward-looking areas of work ought to be less).

"All Peoples" Defence

As just implied, the concept of a fixed annual defence expenditure and its use to create a fixed-sized Defence force tends to create dividing lines between civil and military activities which would have to be made more flexible if one were to follow the concept advocated in this paper. But this division betwen military and civil activities is not relevant solely to the problems of equipment procurement. A much wider issue is also involved; namely, that with a fixed size of Defence force made up of volunteers many of whom make their main career in the Services, the attitude is fostered among the general public that Defence is like Education or Insurance or Bus driving, a field in which people can make a career, which is of some service to the rest of the community (though precisely what this service is is often not clearly understood) and which the rest of the community can take for granted. But Defence is fundamentally different from that concept. It is not, basically, a full-time job for part of the community; it is instead a part-time job for the whole community. In the event of a major war (such as World War II, or Vietnam) the whole community contributes, even though they may not all be in the firing line. Countries such as Israel and Yugoslavia, who are either engaged on intermittent war or live under a very clear threat of war, see their situation in these terms. The Yugoslavs use the phrase "All peoples' Defence" to describe their philosophy of regular Armed Forces backed up by a semi-trained and (when necessary) armed mass of the population.

It would of course be absurd to suggest that Britain is in the same position as Israel or Yugoslavia. But if a war *did* break out, or even threatened to break out, which menaced the survival of Britain, then it would be that much more difficult to mobilise a public opinion nurtured on the idea that their Defence had in the immediate past been adequately met by a fixed all-volunteer force costing an arbitrary £2,000 million per annum. If, on the other hand, Defence expenditure (in money, effort and men) is clearly and publicly conceived as a variable tailored to the Nation's requirements, running down in quiet times and capable of rising again when the need arises, then the concept that Defence is the responsibitity of the whole nation and not just of an arbitrary force of " mercenaries " will be more easily understood.

Deterrence

The vision of a Britain with her " back to the wall " has taken us a long way from the generally accepted image of our current Defence problems. Let us return now to the other extreme, and consider the peacetime role of deterrence which was referred to earlier. Leaving the nuclear deterrent aside as a special case, how much does the deterrent role of the Armed Forces affect the arguments being advanced about the way to plan these Forces ? To a first approximation it does not alter them very much, since in general the sort of forces needed to deter a war are, for obvious reasons, the sort of forces needed to prosecute it if it does, after all, break out. Thus a force structure aimed at covering a range from sudden, short wars to drawn-out wars preceded by rising tension will itself tend to deter a potential enemy from embarking on either type of activity. Of course if money and effort is spent on developing a country's Defence effort on a five-year time scale at the expense of its current Defence posture, this could tempt a potential enemy to favour an unpredictable short war rather than one on a longer time scale. This reaction tends to reduce the degree to which a country could plan for future readiness at the expense of present readiness.

On the other hand, if the requirements for deterrence and for the ability to fight tend to conflict, the latter requirement should normally take precedence since in general the forces required for deterrence do not need to be as strong as those required for the corresponding actual war, due to the factor of uncertainty. For example, the *threat* of a submarine in an area may deter a maritime operation, whereas a *real* submarine is needed to fight it if it actually starts.

Thus in general it is argued that a force suitable for fighting wars is also suitable for deterring them, so that the latter function need not be explicitly considered (except, of course, for the nuclear deterrent which has already been distinguished as a special case).

Implications for Defence Planning

Let us now summarise the argument, and its implication for Defence planning.

It is argued that British Defence thinking is currently based on the following concepts:

(a) A fixed ceiling of Defence expenditure.

(b) All-volunteer Armed Forces.

(c) Maximising the cost-effectiveness of the standing Defence forces to meet any eventuality within the constraints of their size.

It is not argued that this approach is wrong, but that it is not quite the whole truth, and that there is a danger in carrying it too far. An alternative approach to Defence planning, which has a partial validity, recognises that the likelihood of war is continually varying, that the variations can be *expected* (though not of course *guaranteed*) to be on a time scale of years (rather than weeks or months), and that, particularly in periods of comparative quiet such as at present, it makes sense to base Defence planning not solely on maximising the effectiveness of current forces (which if the hypothesis of " quiet " is correct are unlikely to be used in actual war), but also on maximising the chance of building up strong forces over the next few years should the world situation start to turn for the worse. The implications of this approach include:

(a) Proportionately rather more expenditure on " long lead " items of equipment, on the *capacity* to produce and maintain equipment, and on the capacity for training.

(b) A deliberate and logical policy to carry out some research and development on equipment with a "long lead" time, with the intention *not* to put it into production unless the general tension changes.

(c) A more flexible boundary between civil and military activities, both in the field of equipment development and production, and with regard to manpower for the Armed Forces.

There is, of course, a real danger of overestimating this viewpoint. The "Five Year Plan" suggested earlier in this article was deliberately exaggerated in order to try to bring out the implications of such a plan more clearly. The trouble is that, in an era of declining defence expenditure (in real terms) all the vested interests are reinforcing the current concept of Defence. The military themselves like it because it maximises the ratio of "teeth" to "tail", gives them stable career structures and keeps morale up for training purposes (with the emphasis on unpredictable attack by an enemy). The other Government departments like it because a predictable, steady budget for defence is in line with predictable, steady budgets for housing, education and the rest. The general public like it because they are encouraged to believe that they can buy defence for a fixed sum of money and forget about it. In this situation the concept of an alternative approach to Defence planning, admittedly of limited applicability, is in danger of getting lost altogether.

It is not, of course, being seriously suggested that our Defence planners should abandon all their present concepts in favour of a "Five Year Plan" as outlined above. This would be too drastic a step. But it is proposed, for serious consideration, that, *in parallel with current Defence planning based on static expenditure and fixed Forces, a plan should be at least sketched out based on the hypothesis outlined in this article of an expanding Defence effort to meet rising tension.* The two plans could be compared, and in the (probably extensive) areas where they agreed on the current proportions of expenditure on Defence then the policy would remain unchanged. Where they differed, as in the money and effort for research and development, for "long lead" production, and so on, the differences would be drawn to the attention of policy makers who would make decisions based on (hopefully) a clearer understanding of both the short and long term issues involved.

There is a very real chance that UK Defence expenditure, already declining relative to the GNP, will go down still further during the next decade as a result of economic and political pressure (given that the international scene remains relatively calm) a decision which may well be correct. But if we try to maintain balanced forces in this situation, pretending that they will cope with all foreseeable dangers, and do not explicitly plan for a re-building of these forces if the situation starts to deteriorate again, then current Defence planners will lay themselves open to the same obloquy that was (rightly) heaped on the head of military planners who were responsible for our unpreparedness in the 1930s.

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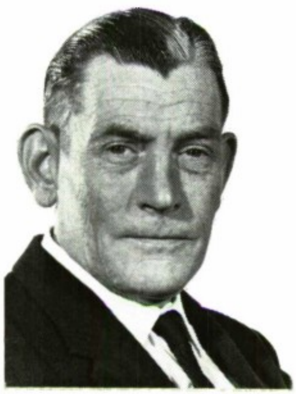
(1) Wood. "Conflict in the Twentieth Century." Adelphi Paper No. 48. June 1968.

(2) *Jane's Fighting Ships*. 1970.

THE COOLING OF DATA HANDLING EQUIPMENT (ADA) H.M.S *BRISTOL*

J. D. Merriman, R.N.S.S.
Admiralty Surface Weapons Establishment



John Merriman transferred to the old Signal School in Haslemere from Portsmouth Dockyard as a draughtsman in 1941.

Appointed AEO through open competition in 1946 and promoted EO in 1951, he has worked on various types of equipment design, specialising in communication antennae for both surface ships and submarines.

Since joining the Ship Systems Engineering group in July 1970, he has been primarily concerned with the Weapons system currently being installed in H.M.S. *Sheffield*.

Introduction

The problems of cooling electronic equipment have been with us just as long as the electronic equipment itself. As long as components remained large, with large surface areas, the problems were, in the main, solvable by moving air in large volumes through the ship and through the equipment. In many cases this was only possible because of limitation in the number of equipments which could be installed in the ship due to their size.

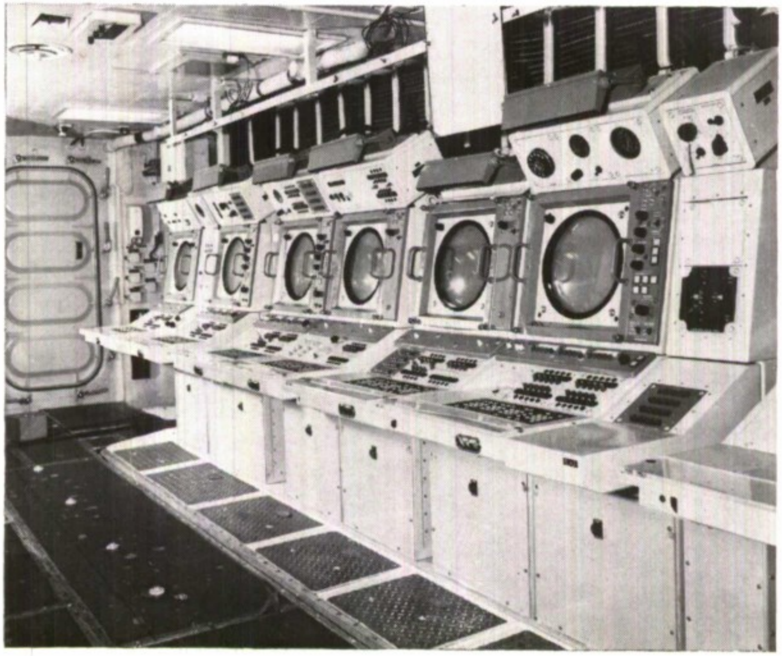
The rapid improvements in component technology brought increasing cooling difficulties. Discrete components became smaller and eventually solid state, finally disappearing in large areas of equipments to be replaced by integrated circuit devices accumulated on printed circuit boards. It became obvious that the circulation of external air was *per se* undesirable because of the inherent risk of dust accumulating across printed wiring and printed board edge connectors. Additionally, higher packing density of circuitry allowed many more equipments to be fitted. There was thus a requirement for larger air trunking and more stringent air filtering resulting in wastage of space and an increase in ambient noise.

Chilled water is becoming increasingly available as a medium for heat transfer in H.M. Ships, and its use is advocated by D.G. Ships, particularly in air conditioned offices. D.W.R.D.S., therefore decided that the Data Handling Equipment under development for H.M.S. *Bristol* would be designed to accept direct chilled water. Concern was expressed that this would result in condensation in and on the outside of equipments in view of the low temperature of the heat transfer medium compared to the relatively high dew point temperature of the ambient air in the air conditioned offices in which the equipment would be housed.

Various methods of avoiding condensation are employed—*e.g.* thermostatically controlled by-pass valves, re-circulating secondary air systems with thermostatic control, re-circulating secondary tepid water systems etc. Most of these systems require a considerable degree of setting-up and installation.

This article describes the method of cooling used in the Automatic Data Handling equipment installed in H.M.S.*Bristol* and variants of the same basic equipment—*i.e.* Computer, Peripheral and Display Systems in H.M.S. *Sheffield* and other Destroyers and Frigates, and a trial conducted in the Weapons System Building at A.S.W.E to determine the correct quantities of chilled water required to obtain efficient cooling without condensation.

Display Consoles installed in the Weapons System Building, A.S.W.E.



Display Consoles installed in H.M.S. *Bristol*. Note, chilled water services run under the portable chequered footplates in front of displays.

The Weapons System Building at Portsdown

As "first of type", the *Bristol* complex would have been an untried system. Therefore a prototype system was installed in the Weapons System Building at A.S.W.E., Portsdown, well in advance of the *Bristol* installation. Conditions in the Weapons System Building simulate, so far as possible, the environmental conditions designed into the Computer and Operations complex of a Guided Missile Destroyer by D.G. Ships. Chilled water for equipment cooling is circulated at 6·7°C to 8·9°C and the ambient conditions are controlled by means of air conditioners in the walls of the building. Double doors minimise the ingress of air, and strict attention is given to cleanliness, including the prohibition of smoking. It has been found, however, that the air conditioners are sometimes unable to cope with the extreme conditions of humidity often prevalent in the clouds at Portsdown.

With an outside recorded relative humidity of 90% an inside relative humidity as high as 75 - 80% is not unusual.

The designed conditions for a D.G. Ships air conditioned compartment are 29·4°C Dry Bulb Temperature (maximum), 21·7°C Wet Bulb (maximum) giving 50% relative humidity and 18°C Dew Point Temperature. These conditions pertain to the extremes which may be experienced, for example, in the Persian Gulf.

The Weapons Systems Building is divided into two floors. The lower floor houses the computer and its associated interfaces, and the upper floor the Display System—*i.e.* a simulated Operations Room. Additionally, the building contains various Radars associated with the complex as well as offices, maintenance rooms and plant rooms.

Description of Equipment

There are two basic types of equipment; Cabinets and Consoles. The cabinets house the Computer, its associated Store and Interrupt equipment, the Computer Peripheral Equipment, and Display Central Equipment. The latter is an interface between the Display Equipment, the associated Radars and the Computer, and although dimensionally different is of similar mechanical construction to the Computer. Consoles house the Displays, namely Labelled Plan Displays and TOTE Displays, and are designed for seated operators with desks extending over their knees. Typical cabinets and consoles are shown in the photographs.

A decision had been taken early in the development that all equipments would be cooled by taking chilled water directly into heat exchangers in each cabinet. This was regarded in some quarters as contentious and somewhat risky. However, it was considered that the advantages outweighed the risk of condensation, which by good design of the cooling systems, could be eliminated.

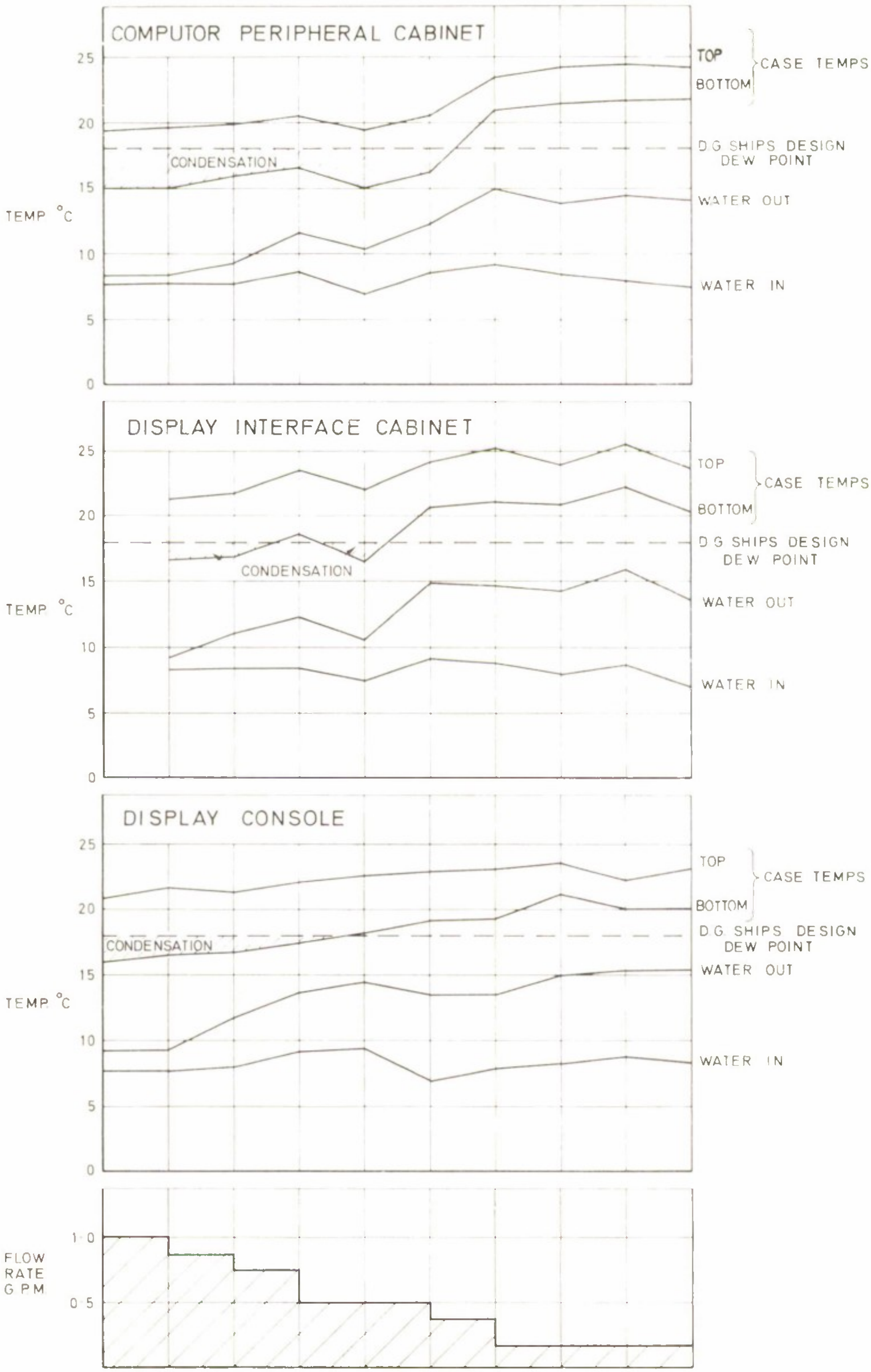
The method of cooling is identical for all Cabinets and Consoles. A heat exchanger is fitted in the bottom, and chilled water is passed through it. Air is blown through the heat exchanger and over the electronic cards and modules, which are arranged to lie in the direction of the air flow. The air is recirculatory, the Cabinets and Consoles being, so far as practicable, sealed from ambient atmosphere. The cooling thus depends upon the transfer of heat from the equipment to the circulating air, and thence through the heat exchanger to the chilled water system. There are no thermostatically controlled switches or by-pass valves, equipment cooling depending upon the correct balance of heat transfer across the heat exchanger. All the heat exchangers are of the same capacity irrespective of the load to be applied. Associated with each Cabinet and Console are screw-down valves on the inlet and outlet pipes of the chilled water system. The water flow rates into the Cabinets and Consoles are controlled by CONSTAFLO valves, which meter specified quantities of water and are non-adjustable. The flow rates into the equipments on H.M.S. *Bristol* and in the Weapons System Building were based upon power ratings issued by the manufacturers. These were subsequently shown to be estimates all of which erred on the high side.

Description of Trial

It was noticed that the outside surfaces of some of the Cabinets and Consoles in the Weapons System Building were wet, particularly during conditions of high relative humidity. This was prominent on the lower part of Central Display Equipment, and on the faces of the Display Consoles under the operators desks. The Computer, Peripheral Store and Interrupt Cabinets also showed evidence of condensation around the lower sections, but to a lesser degree. If a printed card was withdrawn from any of the equipments for maintenance, it immediately misted over. Condensation can only occur when the surface temperature is below that of the dew point of the air in contact with that surface. In an electronic cabinet, condensation will occur if the air circulating within the cabinet has a higher dew point than the surface over which it flows. Since the air leaving the heat exchanger cannot have a dew point higher than its dry bulb temperature, the only condition under which condensation can occur within the cabinet is when office air at a relatively high dew point is allowed to enter and this cannot be avoided. This is clearly unacceptable, and it was obvious that the equipment under review was being overcooled.

A trial was set up to investigate the problem, and to effect a remedy.

The first step was to measure the inlet and outlet temperature of the chilled water pipes and to determine the rate of heat transfer. Coupled with this, the equipment case



Relationship between Water Flow Rate and Temperature of Three Typical Cabinets.

temperatures were measured at selected points, the air temperatures within the equipments where practicable, and the ambient office conditions adjacent to the relevant Cabinet/Console. Since the equipment was operational, it was not possible to carry out a fully instrumented heat run.

Flow meters were then inserted in the chilled water supply pipes, and the flows gradually adjusted until a suitable heat balance was achieved. This proved difficult because the screw down valves were very insensitive at reduced flow rates, the actual flow varying from 0·2 gpm to 0·5 gpm on the same setting.

Having assessed the probable flow rates using this method, the trial was repeated using a selected range of CONSTAFLO valves.

Results

Table 1 summarises the pre-trial condition of a selection of equipments.

It should be noted that with the flow rates of 7/8 gpm and 1 gpm the temperature rise of the water was in two cases less than 1°C, effecting a heat transfer of only 300 watts into the chilled water main.

DG Ships require that the equipment be designed for a temperature rise of 6·6°C between the inlet and outlet pipes of the chilled water supply for the actual heat dissipation of the equipment.

Flow rates were reduced until the temperature differentials approached this figure. Fluctuations in the water supply prevented subjective measurement, but it was apparent that $\frac{3}{8}$ gpm or $\frac{1}{4}$ gpm would be required.

With a $\frac{3}{8}$ gpm CONSTAFLO control in the supply to a Display Console, the minimum case temperature did not rise above the 18°C dew point. It was therefore decided to standardise on $\frac{1}{4}$ gpm throughout, if possible, the ultimate aim being to simplify ship installations.

TABLE I.

Equipment	*Water Flow Rate gpm*	*Temp Rise of Water °C*	*Heat Transfer*		*Min. Case Temp*	*Condition (Bottom of case)*
			Btu/Hr	*Watts*		
Peripheral Cabinet	7/8	1·8	1690	490	16·5	DAMP
Computer Store	7/8	<·1	900	280	16	DAMP
Display Central Equipment	1	<·1	1080	312	15	VERY WET
Display Console	1	1·5	1620	475	16·5	VERY WET

In this condition the minimum case temperature is in every case lower than DG Ships' compartment design dew point temperature of 18°C. These temperatures are at the bottom faces of the Cabinets and Consoles adjacent to the heat exchangers.

The air temperatures within the cabinets were also below the design dew point temperature, and in each case the water inlet and outlet pipes and the heat exchanger blocks were saturated.

The average ambient dew point temperature in the Weapons System Building varied from 16·5°C to 18·5°C during this period.

$\frac{1}{4}$ gpm CONSTAFLO controls were inserted in the supplies to the equipments listed in Table 1. These equipments are typical for H.M.S. *Bristol*, the Computer Store being the most heavily loaded electrically.

Typical results are shown for three of these equipments. The curves are not plotted sequentially, but are taken from a series of figures recorded between August and October 1970.

Only the temperatures of the chilled water inlets and outlets, and the temperature at the top and bottom of each equipment case is shown for clarity. Intermediate case temperatures fall within these ranges. The water flow rate is common to each curve.

TABLE 2.

Equipment	*Water Flow Rate gpm*	*Temp Rise of Water °C*	*Heat Transfer*		*Min. Case Temp*	*Condition (Bottom of Case)*
			Btu/Hr	*Watts*		
Peripheral Cabinet	$\frac{1}{4}$	5·6	1510	440	20·2	DRY
Computer Store	$\frac{1}{4}$	6·5	1750	520	20·4	DRY
Display Central Equipment	$\frac{1}{4}$	5·4	1500	440	20·2	DRY
Display Console	$\frac{1}{4}$	6·2	1670	490	20	DRY

The designed dew point temperature of an air conditioned office is shown, and the points at which condensation will occur indicated.

Table 2 shows the post trial conditions of the equipments.

Spot checks from time to time since October 1970 have confirmed that the equipments are adequately cooled with the temperature rise in each heat exchanger within the 6·6°C specified.

Tactical Display.

Conclusions

(1) It was observed during the trial that the mean case temperature remained at a fairly constant temperature above the mean temperature of the heat exchanger block, allowing for variations in ambient. This effect was also noticed on the Peripheral Cabinet, during the environmental trials, when, with the office ambient at 55°C the mean temperature of the block rose to 20°C but the equipment temperature rose to only 29°C.

(2) By regulating the flow of water to give a rise of 6°C across the heat exchanger, the minimum case temperature in each equipment is above the designed air-conditioned office dew point temperature of 18°C.

(3) Even in extreme conditions of high relative humidity, the equipments, both internally and externally, are now completely free from condensation. Exceptionally, the chilled water inlets and heat exchanger manifolds are wet, but this is being overcome in production by thermal insulation.

(4) The rate of heat transfer to the chilled water main appears to be optimised at 500W, regardless of flow rate, within the specified 6·6°C temperature rise across the chilled water main. Power loading will vary from 0·4 KVA to 0·8 KVA (measured), the latter being the maximum, when all the logic in a peripheral cabinet is switched to +ve. It is significant that the higher flow rates do not equate to more efficient cooling.

(5) It may be concluded that the philosophy of heat transfer direct into the chilled water main without any thermostatic control is practicable if the equipment power loading is known, a satisfactory balance of transfer

obtained across the cabinet and its heat exchanger, and the correct water flow rates specified.

If the relationship between equipment temperature and mean heat exchanger temperature can be established during development, the water flow rate can be specified with a high degree of confidence. The installation problem then resolves itself into a choice of pipe size and CONSTAFLO valve.

The trial confirms that to obtain efficient cooling without condensation, 1 kW of heat will require 0·5 gpm for a temperature rise of 5° - 6° across the chilled water main dependent upon the efficiency of the system. It is considered unlikely that an increase in flow rate through the heat exchanger will effect a greater heat transfer but a higher flow rate will increase the possibility of condensation.

Care must therefore be taken to determine the actual heat load to be dissipated and the flow rates set accordingly to give the required 6·6°C temperature rise.

It is considered that sufficient attention is seldom given to the problems of cooling during the early stages of design. The problems of condensation and air flow could be eliminated if design criteria as regards temperature and air flows are clearly defined in the Development Specification. For example the critical temperature of any electronic component is in excess of 40°C, therefore the return air in a cabinet using recirculating air can be allowed to rise to at least 32°C, and the air supply temperature maintained at, say, 21°C, the air flow rate being such that these are the limiting temperatures. If the air temperature leaving the heat exchanger is 15°C, a controlled quantity of air could be allowed to by-pass the heat exchanger, and mix with cold air to raise the combined input temperature. The air velocity through the heat exchanger must never exceed 450ft./min.

(6) An apparent anomaly is the requirement for all equipments to operate in office ambients of 55°C. It has been found that excessive quantities of chilled water have been sometimes specified to cater for this condition. Since the equipment cooling and the office air conditioning are derived from the same plant, the condition is difficult to simulate and not very realistic. By calculation however, the heat gain through the walls of a computer or peripheral cabinet will increase the internal ambient in the cabinet by approximately 6°C, given a constant mean temperature of the heat exchanger block, when the office ambient rises from 20°C to 55°C. A possible side effect is the likelihood of an increase in moisture precipitation. The question of ambient conditions is now under the scrutiny of TP13.

(7) Accepting that a satisfactory solution to the problems of condensation may be achieved in existing circumstances, the limitations of chilled water temperature and the allowable rise across the heat exchanger block could still cause design problems. A marginal increase in either or each would allow equipment designers that modicum of extra latitude which is so often not obviously required until the point of no return.

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PROJECTILE LAUNCHER FOR WATER EXIT STUDIES

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After serving at TEE Greenock he transferred in 1958 to ARLE Glen Fruin (then AHBRE) where he has been principally concerned in the design of equipment for hydrodynamic research.

Abstract

This article describes the development and operation of a variable angle projectile launcher recently installed at A.R.L.E. Glen Fruin as a facility for examining the stability of models of submarine launched missiles during the underwater trajectory and water-air transition phases. It is powered by a compressed air/vacuum system and has been successfully used to launch missiles weighing up to 40lb. at velocities of up to 125ft./sec. over a wide range of exit angles, using quite moderate pressures. The ultimate capability in terms of payload and velocity has yet to be evaluated.

Introduction

During the early part of 1969 A.R.L.E. Glen Fruin, which previously had been mainly concerned with water entry facilities[1] was requested to investigate the feasibility of extending the facilities to include a water exit launcher for which a future requirement had been anticipated.

This extension of facilities was required to provide a means whereby the underwater trajectory of models of submarine launched missiles and their passage through the water/air interface could be studied. For this programme of tests the main objective was to provide information concerning the stability, forces and moments and the determination of empirical data, over a wide range of exit velocities, exit and pitch angles which at a later stage may be used in the building of a mathematical model of the underwater and water exit behaviour.

The first stage which is now complete was planned to be carried out in calm water conditions while the second stage, in simulated waves, is scheduled for later this year when a standing wave making facility is installed.

Since an appraisal of the specification and a survey of the main tank structure indicated that there was no inherent difficulty, a contract for a design study was placed with a firm which had considerable experience in the design and development of somewhat similar equipment now used in the aircraft industry for assessing damage to jet engine air intakes, airframe sections and windscreens resulting from bird strikes.

On completion of the design study the requirement for such a facility had become much more urgent but the firm concerned, because of other commitments, could not undertake to meet the completion date specified. At this stage following design modifications it was decided that the launcher should be constructed at A.R.L.E. Glen Fruin and in fact it was completed on schedule.

Because of the urgent need to have this facility operational for feasibility studies on new weapon proposals, much earlier than had been anticipated, certain desirable refinements which would have simplified its operation had to be postponed. It has now been successfully used for some 150 launchings and these modifications together with others which came to light during trials will be effected when time is available.

The launcher is situated in the main tank, 150 long × 30 feet wide × 40 feet deep, of which practically all of one side is fitted with 30 inch square panels of armoured glass. To maintain a high degree of clarity and optimum colour, necessary for underwater photography, the one million plus gallons of water are continually circulated and chemically treated. There are a number of cable termination positions on the tank side which are linked to a nearby control room equipped with a wide variety of recording and support instrumentation.

Description and Operation of Launcher

A general view of the launcher and missile arresting system is illustrated in Fig. 1.

The gun itself consists of two steel tubes arranged as illustrated in Fig. 2. The inner tube (the gun barrel) 14 ft. long × 10·75 in. outside diameter × ·375 in. wall thickness, which carries the test missile supported in a sabot is partially evacuated while the outer tube (the pressure chamber) 7 ft. 6 in. long × 18 in. outside diameter × ·344 in. wall thickness is pressurised with compressed air.

In adapting the Design Study proposals the primary considerations, in addition to performance requirements, were the early completion date, ease of production, and minimal cost. Given that the gun barrel was to be approximately 10 in. bore × 14 ft. long and that a separate compressed air chamber of similar net volume was required, it was a simple step to the conception of two concentric tubes, in readily available standard sizes. In order to connect the tubes, a plate was welded to the outside of the gun barrel and a ring was welded to the forward end of the pressure chamber, thus permitting a bolted

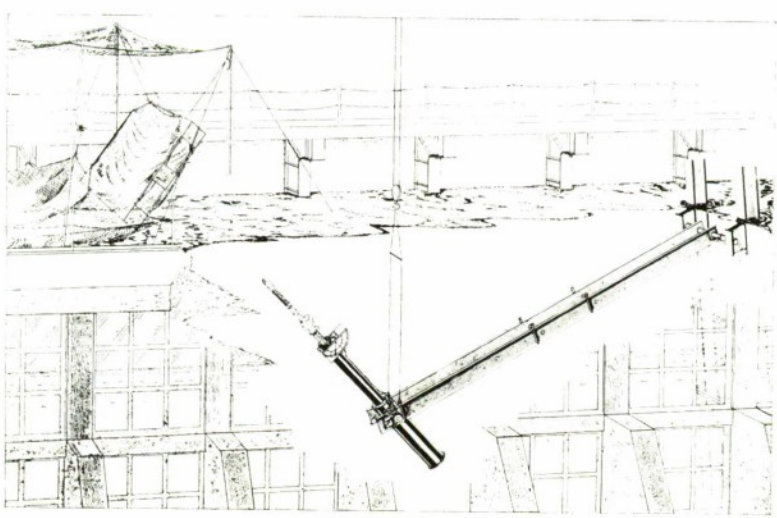


FIG. 1. Projectile Launcher for Water Exit Studies.

joint. A similar ring at the after end is used to attach the access door. "O" rings are employed to make peripheral seals, these being preferred to face seals because the lower bolt loads aid assembly of the access door. To counter the cantilever loads of the two tubes, four radially disposed adjustable struts are provided at the after end of the vacuum tube, to bear loosely on the inside of the outer tube.

The vacuum tube is sealed at both the breech and muzzle ends by means of polyester diaphragms, the thickness of which can be varied to suit a wide range of launching conditions. A bolted ring clamps the diaphragm between an "O" seal and a flat rubber ring. As a further precaution against creep of the diaphragm under load, the inboard metal face has machined in it a series of shallow concentric grooves into which the diaphragm is forced by pressure of the rubber ring.

to a vacuum pump and compressed air reservoir, the conditions being monitored on a Control Board (Fig. 3) beside the tank. Arrangements are being made for the control board to be modified so that the facility can be operated remotely from the Control Room.

The bore of the gun barrel was honed to remove millscale and excrescences and although neither truly round nor smooth it has nevertheless proved adequate for the purpose of firing sabots containing missiles. The sabots will be discussed in some detail later.

The firing of the gun is by means of an electrically ignited ring cutter detonator which is secured by adhesive tape to the diaphragm separating the pressure chamber and gun barrel. This detonator has a circular form, a little less than the bore diameter and when fired has the effect of completely removing the

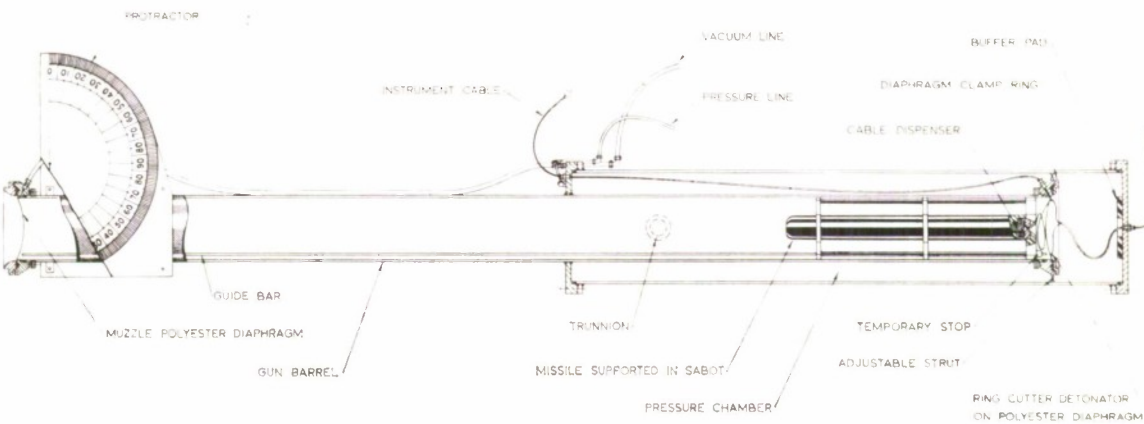


FIG. 2. Section through Gun Illustrating Typical Missile and Sabot.

The gun can be supported at any angle in the vertical plane along the axis of the tank, from a number of positions between the parallel arms of a lifting frame, formed from 15 ins. × 4 ins. steel channel section. The angling gear consists of a manually operated single reduction worm gear, the wheel being keyed directly to the gun trunnion shaft. The lifting frame in turn is pivoted from brackets mounted on an existing catapult support structure, a 5 ton gantry crane being used to lower the gun frame to the required operating depth. As an aid to setting the angle, an 18 ins. radius protractor provided with a plumb bob is fitted at the muzzle end.

The gun barrel and pressure chamber are connected by nylon tubing of $\frac{3}{4}$in. outside diameter and $\frac{3}{8}$ in. outside diameter respectively

diaphragm, thus exposing the sabot to the combined effect of the charge pressure and a partial vacuum. The vacuum is restricted to 28 ins. Hg to reduce the pumping time and incidentally this avoids the risk of erosion of the nylon tubing which begins at over 28 ins. Hg. The diaphragm at the muzzle is removed by the missile during its passage. In order to test the continuity of the firing circuit a Safety Ohmmeter is used, and in addition, a safety plug is kept in the possession of the gun operator and not placed in the circuit until other personnel have cleared the firing area. Other warning systems and barriers are employed to reduce the risk of persons entering the down-range area inadvertently.

There is a need when the behaviour of finned missiles is being investigated, to prevent

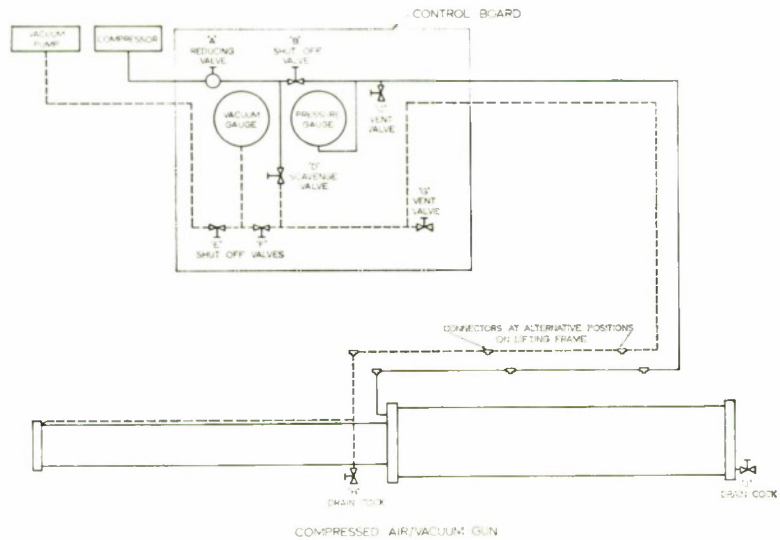


FIG. 3. Air Pressure and Vacuum Circuits.

rotation of the sabot during the acceleration stroke. A half-round section guide rail attached to the inside of the barrel and a corresponding groove in the sabot serve to keep the missile correctly aligned. A notch is provided at the breech end of the rail into which can be keyed a temporary back stop to hold the sabot off the diaphragm.

Glands are provided for electric cables for connection to missilc trailing cable and detonator circuit.

The Purpose and Use of Sabots

The term sabot is used to describe a carrier vehicle in which a variety of missile shapes and diameters can be accommodated within the same gun barrel. A sabot should be constructed as lightly as possible and have a relatively blunt front face so that under conditions when it is ejected from the gun, because of the resulting high impact forces due to encountering the water it is soon retarded. Thc disadvantage of having to accelerate a greater mass than the missile alone is outweighed by the manner in which the sabot inhibits the air blast from affecting the missile's water flight.

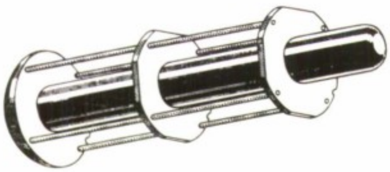
Whether or not the sabot is ejected at the end of the power stroke is dependent upon the resultant force arising from, on one side, the charge pressure and the momentum it gives to the sabot, and, on the other side, the combined effect of the back pressure of the air plus the hydrostatic, hydro-dynamic and atmospheric pressures. *To quote an example:* at a relatively low charge pressure the sabot will only partly emerge and will then be forced back down the gun barrel.

The sabot is constructed so as to hold the missile correctly aligned with thc axis of the gun, retain it firmly and prevent its rotation during the acceleration stroke, yet offer minimal resistance to the departure of the missile with the onset of retardation of the sabot.

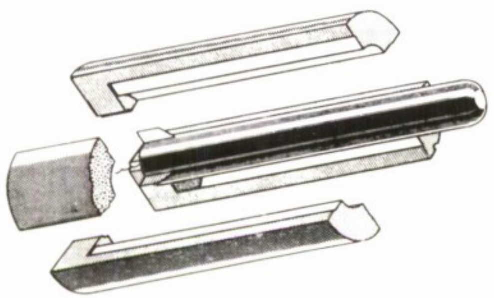
Where umbilical cables are employed to monitor conditions within a missile during the water to air phase, it is necessary to have the rear plate of the sabot pierced to allow for the passage of the sabot over the cable, between the missile and the cable anchor in the gun barrel. Furthermore, if the exit velocities are high enough to ensure ejection of the sabot it may be desirable to use a split sabot so that in separating after ejection, its separate parts would be less likely to foul the umbilical cable.

Sabots may be manufactured in a variety of configurations and materials. Three types of sabots are illustrated in Fig. 4 (a), (b), and (c). Sabot (a) is of one-piece construction, *i.e.* non-separable, made from synthetic resin laminates and aluminium alloy rods. Flats are provided on the forward and intermediate diaphragms to provide air passages to reduce pressure build up ahead of the moving sabot. This sabot weighs 15 lbs. and is non-buoyant but its shape lends itself to ease of recovery.

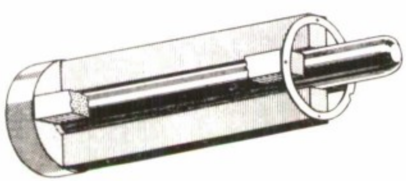
Sabot (b), made of moulded rigid polyurethane foam, is split longitudinally into four pieces so that a finned missile can be fired



(a) ONE-PIECE NON BUOYANT SABOT



(b) SEPARABLE BUOYANT SABOT



(c) ONE-PIECE BUOYANT SABOT

FIG. 4. Sabot Configurations.

without its water flight being unduly affected by the sabot, the component parts of which are designed to separate in the event of the sabot being ejected. This sabot has good buoyancy and weighs only 9 lbs. but since it has a relatively higher volume than (a) its weight advantage is offset by the higher back pressures it will produce; moreover its low mechanical strength renders it susceptible to damage.

Sabot (c), of one-piece construction, is made of a rigid plastic micro-balloon material with an aluminium alloy front ring to keep the four legs in their correct relationship. Like (a) it provides air passages to reduce pressure build up. Weighing 17·5 lbs., it has moderate buoyancy, but is less robust than (a).

Arrester Nets

Because of the problems of retarding missiles from high velocities in water, there were misgivings when attention was turned to the need to arrest missiles in free air flight. Two lugs were provided at the breech end of the barrel to do duty as anchors for a nylon rope retarder in case all else failed. In fact the methods of retardation tried, all using nets woven from nylon rope, have proved adequate in arresting missiles without damage, so the lugs have subsequently been removed.

In the first of two methods illustrated, Fig. 5, two nylon nets are slung, one above the other, so that they hang in a deep catenary, the lowest point of which is over the water exit position of the missile. The emergent missile, upon first encountering the net, meets little resistance but as the velocity is reduced, progressively more and more of the net is raised until the missile's forward momentum has been spent. It then drops gently back into the water.

The second method illustrated avoids the secondary arresting problem presented by a non-buoyant missile which would proceed, if unchecked, to the tank bottom. In this method a net is also slung over the water to hang in a gentle catenary, but another is placed about 15 ft. above it. In addition a wooden framework 10 ft. square is arranged to intercept the missile in free flight by means of two nets held in the frame by ligatures. As the ligatures break, the nets wrap themselves round the missile which, blunted and slowed, is thus more easily arrested by the upper net, finally dropping gently onto the lower one.

METHOD 1 METHOD 2

FIG. 5. Arrester Nets.

Sequence of Preparation and Firing

The missile in its sabot is breech-loaded, the back stop is fitted, electrical connections to the missile are made, then polyester diaphragms are clamped to breech and muzzle ends of the vacuum tube.

A ring cutter detonator is applied to the after diaphragm and its two wires are connected to the firing circuit, the cable for which passes out through a gland in the centre of the access door. The circuit having been proved, the door is then bolted in position.

The gun is rotated by the angling gear until the required lifting frame/gun barrel angle is obtained, then the launcher is lowered into the water until the protractor on the gun indicates the desired trajectory angle.

The electrically driven vacuum pump (Fig. 3) is started up and valves "E" and "F" are opened to expose the gun barrel to the vacuum. The time taken to achieve a vacuum of 28 ins. Hg is approximately five minutes, and this attained, valve "E" is closed and the pump stopped.

By opening valve "B", compressed air is then admitted to the charge barrel, *via* the air reservoir and reducing valve "A", until the air pressure reaches a predetermined value, when valve "B" is closed.

A safety plug is inserted in the firing circuit and if normal checks on electrical continuity are satisfactory, isolating valve "F" is closed, the countdown to the moment of firing commences, and cameras and recorders are set in motion. Firing is by means of a push button switch in the Control Room.

In the event of a misfire, the compressed air and vacuum lines can be vented by opening valves "C" and "G" respectively, so that the gun may be brought to the surface without danger to personnel.

After firing, water floods the gun barrel and part of the charge barrel until the pressures of in-rushing water and entrapped air are in equilibrium. Upon the gun being raised to the surface, therefore, it is necessary to open drain cock "J" to drain out the water. This done, the gun may be readily angled to a convenient attitude for making preparations for the next shot.

Once the remnants of the used diaphragms have been removed, water in the vacuum line and gun barrel is blown out with compressed air by opening drain cock "H" and scavenge valve "D", while isolating valve "F" remains closed.

With the present system, four shots a day are possible.

Factors Affecting Gun Performance

Fig. 6 illustrates the theoretical state where the charge air would expand adiabatically while the residual air in the partly evacuated barrel is being compressed adiabatically as the sabot and missile travel towards the muzzle. When the missile pierces the water seal, the pressure ahead of the sabot rises to the value of the static back pressure, but the pressure behind the sabot continues to fall until the pressure differential reaches an instantaneous zero only to widen again to produce a deceleration force. This event, indicated at "X", occurs after more than 12 feet of travel.

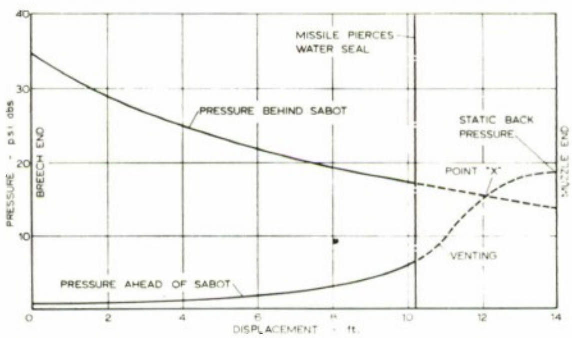


FIG. 6. Curves of Theoretical Adiabatic Expansion for a Typical Missile and Sabot Combination.

Fig. 7 is derived from an actual shot record where an umbilical cable gave a continuous record of acceleration from an axially disposed accelerometer mounted in the missile. The velocity and displacement curves were obtained from the acceleration curve by graphical integration, and highlight the fact that the acceleration reached zero at a displacement of 9·1 ft., *i.e.* about three feet earlier than the theoretical curve's point "X". This discrepancy is thought to be due mainly to the fact that the sabot is not fitted with piston rings so that blow-by of charge air causes a reduction in charge pressure and a rise in pressure in the partly evacuated barrel, with a consequent reduction in efficiency.

From the acceleration curve and the known mass of sabot and missile, the equivalent differential or net pressure may be obtained and compared with the theoretical state, but the complete answer will be to fit pressure transducers as discussed later.

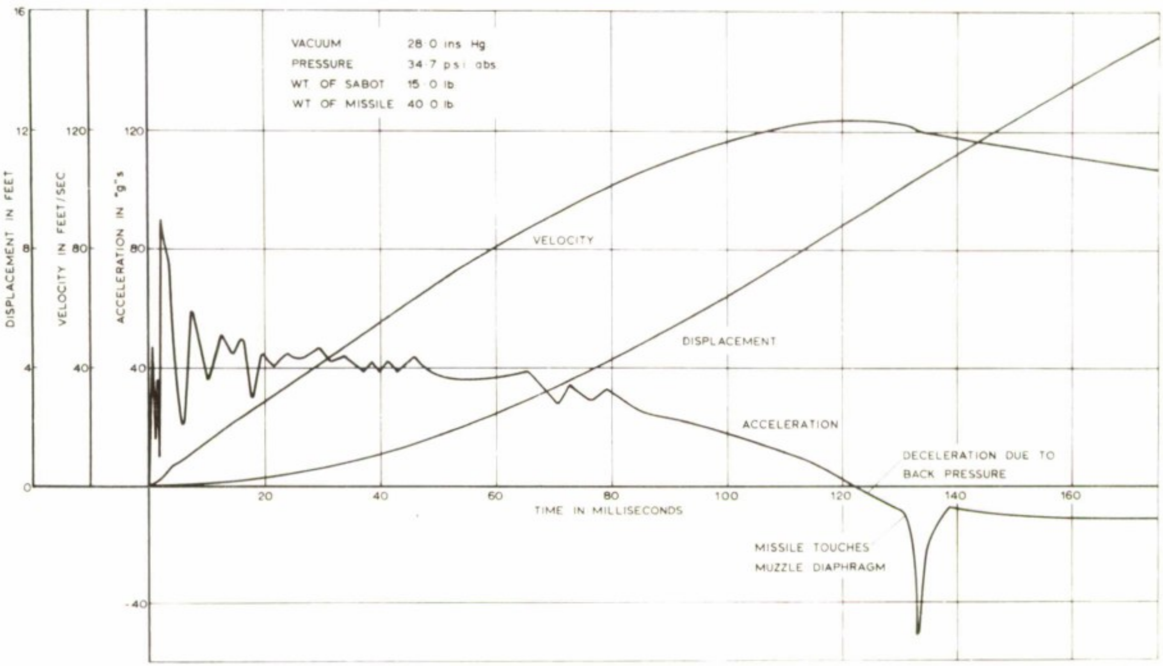


FIG. 7. Plots of Acceleration, Velocity and Displacement/Time.

A further potential source of energy is the detonator which is quoted as having an output of 150 calories. Tests have indicated that this energy does not significantly contribute towards propulsion and it is assumed that it is dissipated as heat.

With the partial vacuums so far employed, the pressure ahead of the sabot rises to a greater value than the static back pressure, hence the muzzle diaphragm must belly out just before being pierced by the missile which on entering the water will be accompanied by a quantity of air. The air, having little momentum, soon loses its forward motion, allowing the missile to travel fairly cleanly to the surface. The far greater quantity of air behind the sabot is prevented from affecting the launch by the presence of the sabot, which will not in every case be ejected. If the launch velocity is high enough, the sabot's own momentum will allow it to be ejected, otherwise it will be thrust back down the barrel by the inrushing water to fetch up against the access door buffer pad.

Tests in which the combined weight of the sabot and missile was 55 lbs., at conditions of 28 ins. Hg in the gun barrel and 20 p.s.i. gauge in the pressure chamber resulted in exit velocities in the order of 125 ft./sec. In order to determine the maximum capability of the gun and the exact point of separation of the missile from the sabot arrangements are being made to fit resistance strain pressure transducers at each end of the gun barrel. This system will give a complete pressure-time history behind and ahead of the sabot.

Data Measurement

There are two relatively simple methods of measurement which are adaptable to this free flight system both of which have been successfully used on many occasions.

(a) The connection, by means of an umbilical cable, of suitably positioned instrumentation, *e.g.*, pressure transducers, accelerometers, gyros, etc., within the test missile to data recording equipment in the form of cathode ray oscilloscope, ultra violet or tape recorders, situated close by. The type of umbilical cable used for this type of work is no more than 0·1 in. outside diameter and is comprised of 12 cores of 33 S.W.G. enamelled copper wire contained in a thin flexible plastic sheath. Its length is variable and it is carried in a cable dispenser which is fitted within the aft end of the test missile as illustrated in Fig. 8. The recorded data which is evaluated on an assessor can then be displayed on a plotting table and transferred to punched tape for further detailed analysis on a computer.

(b) Photography of the complete phase by means of a number of suitably positioned 35 mm high speed cine cameras. Each camera is fitted with a photo electric unit which produces a pulse each time the shutter is opened. This train of pulses is then recorded together with an accurately controlled timing frequency and hence the framing rate can be determined. Synchronisation of events on different cameras is effected by arranging timed flash bulbs to black out a number of frames on each film immediately prior to the first event. This system gives a relatively quick check on angular and lateral deviations and illustrates the formation of cavitation bubbles which may be present. Typical strip prints are illustrated in Fig. 9. While a photoelectric timer unit can be readily adapted to operate underwater to give a direct reading of muzzle velocity it is not always satisfactory in the determination of the water exit velocity due to alignment problems when the missile does not follow a straight line trajectory.

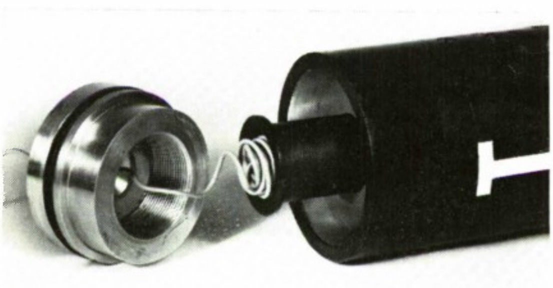


FIG. 8. Trailing Cable Dispenser.

Polyester Diaphragms

The properties of toughness and strength allied to low water absorption and virtual impermeability to air make polyester film ideal as a diaphragm.

In selecting a single thickness of film, or a number of films which combined will give the required thickness for a given pressure the criterion has been to use the elastic properties of the film to the full, *i.e.* up to the point of minimum permanent distortion. This is a reasonable compromise between reliability and economy and is achieved when the length of arc of the bubble, formed when the film is subjected to pressure, is greater than its initial length in the ratio of approximately 1·047 to 1. It follows that for a diaphragm of 10 ins. dia., assuming the form of a partial sphere, the height of the bubble would be 1·34 ins. There remained the task of matching the diaphragm thickness to each pressure condition, while maintaining this bubble height.

So that this investigation could proceed without delaying the firing programme, a Hydraulic Test Rig (Fig. 10) was built using water as the fluid medium and having a form of joint similar to that of the gun itself. The procedure was to test a diaphragm, or combination of diaphragms, by increasing the fluid pressure until the diaphragm just touched the gauge bar set for a bubble height of 1·34 ins.

TABLE 1.

(A selection of results)

Polyester Diaphragm Number and Thickness	*Pressure Recorded p.s.i. gauge*
1 @ ·0015″	2
1 @ ·002″	5
1 @ ·003″	7
1 @ ·005″	14
1 @ 0075″	22
1 @ ·010″	27
1 @ ·014″	36
2 @ ·010″	50
1 @ ·010″ + 1 @ ·014″	53
2 @ ·014″	64
2 @ ·010″ + 1 @ ·014″	74
3 @ ·014″	90

Further tests are being undertaken to assess the feasibility of reducing the energy lost by the missile in piercing the muzzle diaphragm. When subjected to the combined effect of partial vacuum and water pressure, the diaphragm deflects inwards, but reverses towards the end of the acceleration stroke with the change in differential pressure. It was considered that advantage could be taken of this phenomenon by cutting a circular hole in the centre of one diaphragm to be placed on the low pressure side of a plain diaphragm, as in Fig. 11, the holed diaphragm buttressing the

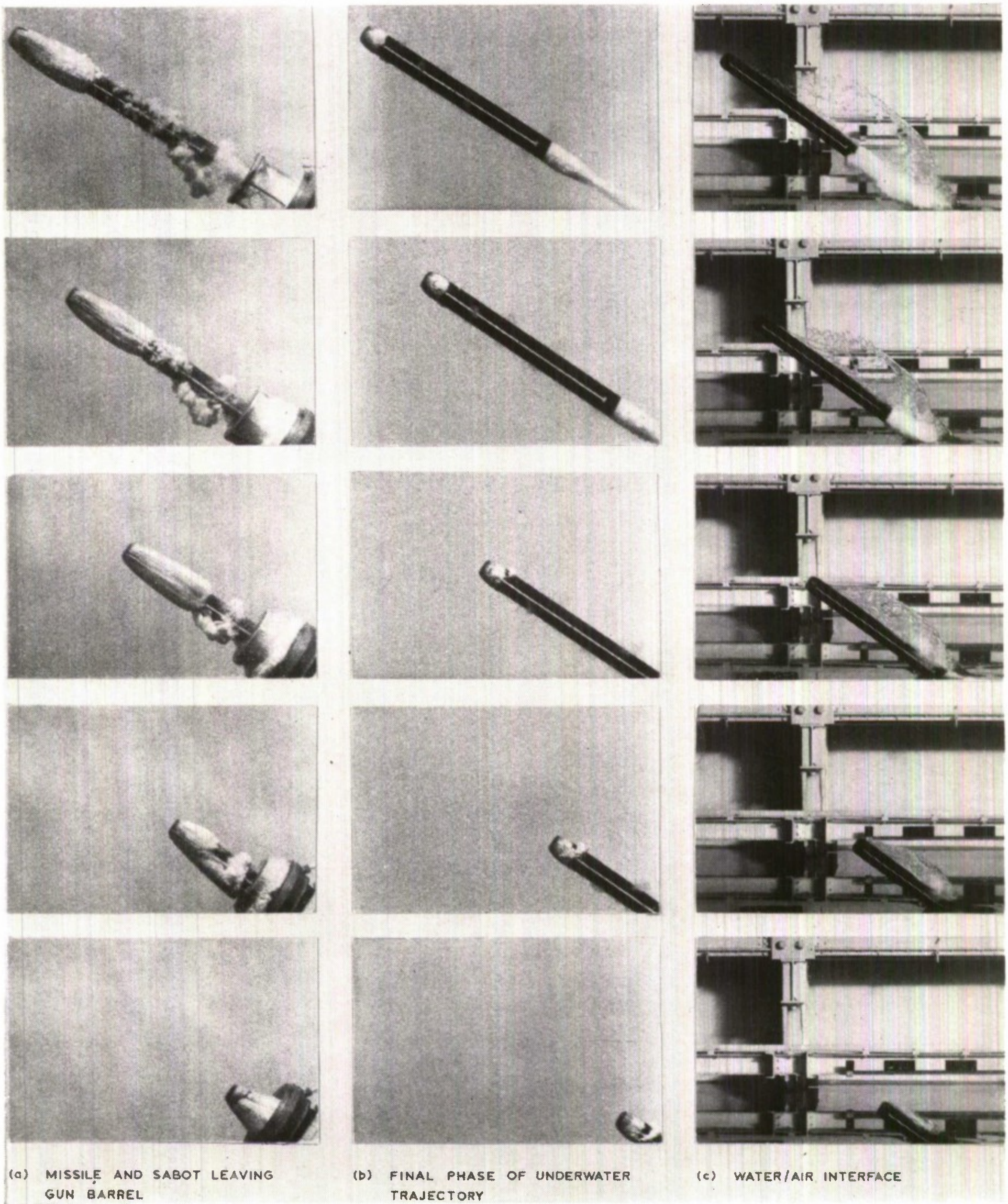


FIG. 9. High Speed Cine Photography Illustrating Typical Sequences.

plain one against the external water pressure but playing a neutral part upon reversal of differential pressure. The advantage to be gained is all the greater if the thickness of the individual diaphragms is less than the thickness of the muzzle diaphragm they replace giving the missile less break-out work to do.

TABLE 2.

No. and Thickness of diaphragms	*Pressures recorded p.s.i. gauge*		
	Condition		
	a	b	c
2 @ ·002″	9·5	9·0	4·0
2 @ ·003″	14·0	13·0	6·5
2 @ ·005″	23·0	22·5	11·0

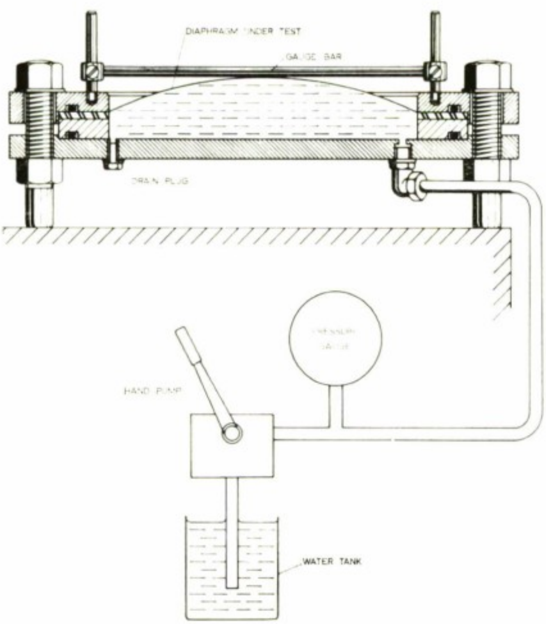


FIG. 10. Hydraulic Test Rig for Polyester Diaphragms.

Table 2 shows examples from the results obtained when dual diaphragms were tested having (a) Two plain diaphragms (b) One plain and one with 1 in. dia. central hole, plain diaphragm on pressure side (c) One plain diaphragm and one with 1 in. dia. central hole, holed diaphragm on pressure side.

Other tests with larger central holes showed that there is some fall-off in strength in condition (b). The results indicate that there is a distinct advantage to be gained by using a holed diaphragm to buttress a plain one and the effectiveness of these measures in reducing the energy lost by the missile in penetrating the diaphragms will be more fully evaluated when time permits by firing a missile fitted with an axial accelerometer through the diaphragms.

Proposed Modifications

It is intended to simplify the launcher to enable more firings to take place within an allotted period and at the same time improve its versatility.

The most important change will be to make the gun barrel length variable from 6 ft. to 14 ft. in a number of steps thus making adjustment of final volume possible as well as the initial pressure. By this means it is hoped that a close approach to the ideal state may be achieved where final pressure is equal to back pressure, and the sabot is ejected, free of the damaging effect of being rammed down the barrel. At the lower velocities, the short barrel length will provide a bonus in the time saved in evacuating the barrel.

Parallel with the above change, will be the provision of an adjustable trunnion position to maintain the equilibrium necessary for effortless angling of the gun.

Other modifications will include a hinge on the access door and a dispenser to be mounted between the breech diaphragm and the sabot. A miniature socket unit on the back of the test missile will receive one of the two plugs at either end of the dispenser coil, the other

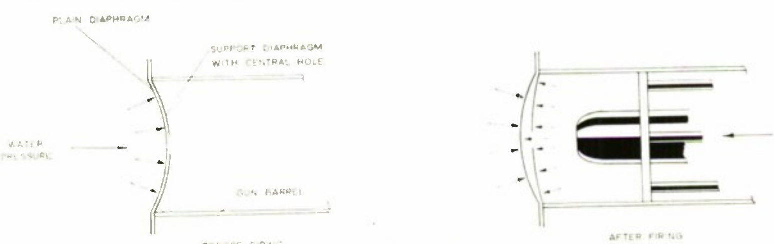


FIG. 11, Proposed use of holed diaphragm at muzzle.

plug being connected into a socket located inside the barrel. The advantage of this arrangement will be that dispenser assemblies could be prepared in advance of a test programme so that no time-consuming rewiring of the missile and its dispenser will be required between firings, with a consequent reduction in re-cycling time.

The tankside Control Board is to be modified so that the conditions of pressure and vacuum can be monitored in the Control Room and, by employing solenoid-operated valves, full and remote control over the operation of the gun can be exercised by the trials officer, this removing the need for personnel to remain in the vicinity of the firing range while a shot is in progress.

Acknowledgement

Acknowledgements are due to colleagues in the drawing office, workshops and laboratories at Glen Fruin for their unstinting work in bringing the first phase of the project to a successful conclusion.

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The New Procurement Executive

The Procurement Executive, Ministry of Defence (MOD(PE)) came into being on August 2nd, 1971 when its Chief Executive Mr. D. G. Rayner, assumed his responsibilities in accordance with Command Paper 4641 on the organisation for Defence Procurement and Aerospace. Mr. Rayner has become a member of the Defence Council.

Nine controllers dealing with specific areas of activity, four of which are Systems Controllers, wholly project oriented, covering sea, land, air and guided weapons and electronic systems respectively. There is also a controller for research and development establishments and research. These five controllers report directly to the Chief Executive whilst the controller for policy, finance, personnel and sales report through the Secretary.

Officers appointed as Systems Controllers and for research are:

Under the Chief Executive and, in addition to Secretary (PE)—

Controller of the Navy (C of N)—Vice Admiral A. T. F. G. Griffin

Master General of the Ordnance (MGO)—General Sir Noel Thomas.

Controller Aircraft (AC)—Air Chief Marshall Sir Peter Fletcher.

Controller Guided Weapons and Electronics Systems (CGWL)—E. C. Cornford.

Controller R and D Establishments and Research CER)—Sir George Macfarlane.

Under CER there are three Deputy Controllers, Mr. B. W. Lythall, Dr. W. H. Penley and Mr. N. Coles, each with a special interest in the Services. Mr. H. L. Lawrence-Wilson has been appointed AUS(ER). Mr. Lythall and Dr. Penley continue as members of the Admiralty Board and Army Board respectively and in addition to their responsibilities as Deputy Controllers under CER act as Scientific Advisers to their Board.

DETERMINATION OF ADDITIVES IN TURBINE OILS

Haridimos Tsagarakis*

Abstract

Methods based on Thin Layer Chromatography (TLC) and instrumental techniques for the separation and identification of additives in turbine oils are described. They were followed in the analysis of used turbine oils to find the concentration of anti-oxidant and anticorrosion additives to determine if any additive depletion had occurred during service.

Introduction. There are many reasons for using additives in turbine oils and one of the most important is to stabilise the oils. The oils, containing antioxidants and rust inhibitors, are normally used for long periods before renewal, and to guard against sudden failure in service the condition of the oil must be assessed periodically.

Many methods for the qualitative and quantitative determination of additives have been described[2, 4, 5, 6, 7, 8] but most suffer from certain disadvantages, particularly in the case of used oils where interference from breakdown products, wear metal concentration and other sources obscure results. Certain modifications in the use of TLC and instrumental analysis have given acceptable results.

Determination of Antioxidant

The antioxidant selected for investigation was 4-methyl-2, 6-di-tertbutylphenol (4M26B)[1], as it is known to be contained in at least one of the turbine lubrication oils used. Because of the arrangement of the alkyl-groups (Fig. 1) this compound is difficult to detect and measure by the more conventional chemical methods. Four different methods giving varying degrees of success were tried. They were based on TLC, colorimetry, infrared spectrometry and gas liquid chromatography (GLC)[2].

Thin Layer Chromatography

The equipment used in this work consisted essentially of components as developed by Stahl[3]. The absorbent was silica gel G. It was prepared by making homogeneous a 50% aqueous suspension by shaking for 60 seconds in a wrist-action shaker. Following the standard procedure an absorbent layer of approximately 250μ was applied to glass plates 5 $\times$ 20 cm and 20 $\times$ 20 cm. The coated plates, after drying in air were heated to 110°C for 30 minutes, stored in a desiccator and used as required. The sample was prepared by dissolving the oil to be analysed in an equal volume of carbon tetrachloride. It was then applied to the coated chromatographic plate by means of a Hamilton syringe with cut-off tips. By experiment 1μl of the mixture was found to be the optimum sample load. After application to the absorbent layer migration was allowed to continue (Fig. 2) for about 60 minutes, at which time the solvent front had approached the far edge of the plate. The plate was then removed and dried in air until free from solvent. When dry, the plate was developed by spraying with phosphomolybdic acid and then heating for five minutes at 50°C. Reddish purple spots appearing on the plate at an Rf value of about 0·7 showed the presence of the additive, while the hydrocarbons travelled near the solvent front (Fig. 3). The size and color intensity of the spots, compared with chromatograms of standard solutions run simultaneously, indicated the amount of additive present in the sample.

Using TLC the antioxidant determination can be made with an accuracy of $\pm$20%. This is sufficient where speed of analysis is more important than precision. Up to 15 samples can be applied to one TLC plate, *e.g.*, five standards with 10 unknowns can be analysed in about one hour.

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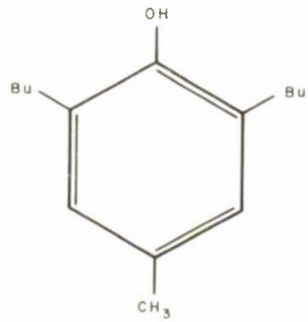

FIG. 1. 4-methyl-2, 6-tertbutyl-phenol.

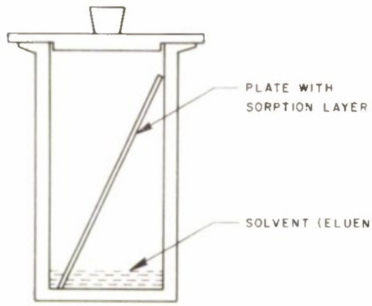

FIG. 2. A separation chamber.

Instrumental Analysis

The methods used involved a preliminary separation of the antioxidant by distillation with aqueous methanol followed by the analysis of the distillate. The analysis followed procedures based on colorimetry, infrared spectroscopy and GLC. The distillate separation was common to all three procedures. 0·5 grams of sample were placed in a distillation flask and mixed with 75 ml methanol and 100 ml. distilled water. The mixture was distilled slowly until 150 ml. distillate were collected. The flask and contents were allowed to cool to 25°C and a further 50 ml. each of water and methanol were added. Distillation was continued until a total of 250 ml. of distillate was obtained.

Colorimetric Method

The colorimetric procedure is based on the formation of the intensely coloured 3,5 3′,5′ tetra-tert-butyl 4,4′ stilbene quinone by the oxidation of 4M26B with lead dioxide. The procedure followed was to transfer 25 ml. of the methanol distillate to a conical flask, and subsequently 65 ml. 88% aqueous methanol solution and 1 gm PbO_2 were added. The mixture was refluxed for three hours, cooled and filtered through a 30F sintered glass crucible. The filtrate was transferred to a 100 ml volumetric flask, 1 ml of glacial acetic acid added and the flask made up to the mark with methanol. Absorbance was then measured at 420 mμ with a Beckman Model DU spectrophotometer using a cell of 1 cm path length.

A calibration graph was made using the following procedure: 0·0, 0·05, 0·1, 0·2, 0·3 and 0·4 ml. of a standard solution containing 0·1 mgm 4M26B/ml in methanol each made up to 70 ml methanol, received a further addition of 20 ml. water and 1 gm PbO_2. These standards were then processed following the above procedure to give the calibration curve of Fig. 4. In methanolic solution the developed colour obeys the Beer-Lambert Law over a wide range of concentrations and is stable for a long period.

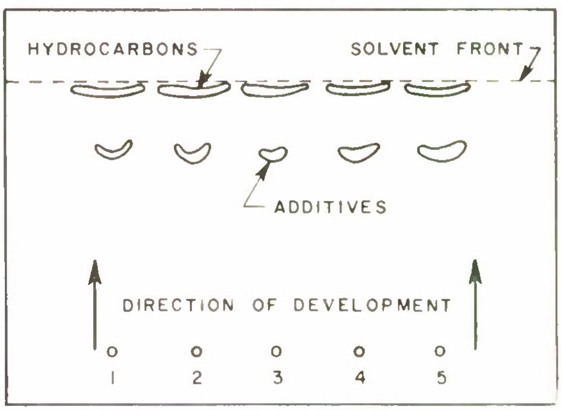

FIG. 3. TLC of turbine oils. Adsorbent: silica gel G. Solvent: CC14.

Columns 1, 2: used turbine oils.

Columns 3, 4, 5: standard solutions containing 2500, 3000, 3500 ppm 4M26B respectively.

Infrared Method

For the IR method the antioxidant was extracted from the aqueous methanol distillate with cyclohexane and the absorbance peak was measured at about 2·8μ after scanning through the region 2·5 to 4μ. The instrument used was a Perkin-Elmer Model 221 IR Spectrophotometer with a capillary action NaCl cell having a fixed path length of 3 mm. The procedure followed was to transfer the total (250 ml) aqueous methanol extract to a 500 ml volumetric flask. This was diluted to about 450 ml. with water. 5 ml. of Spectrograde

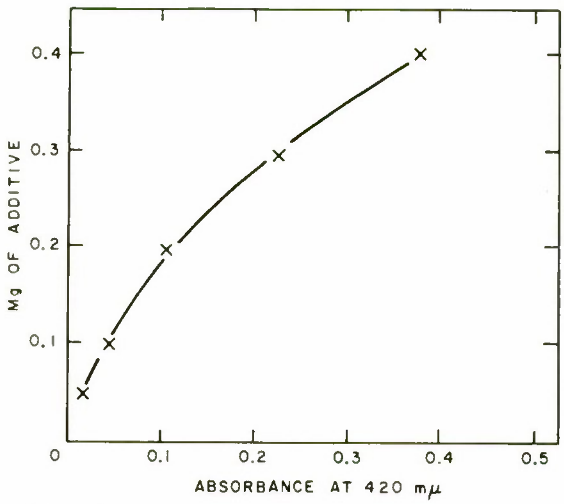

FIG. 4. Calibration graph.

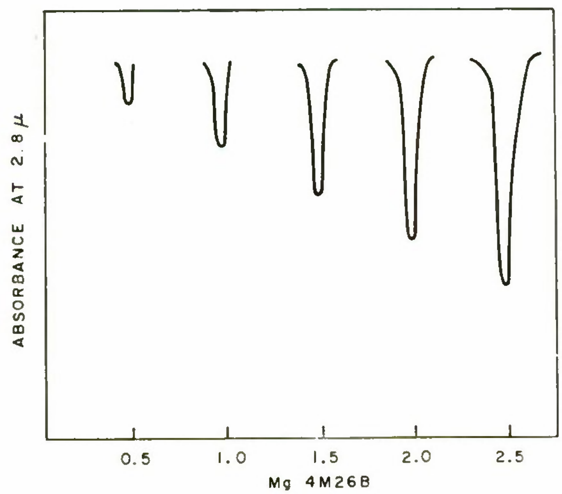

FIG. 5. Calibration results IR.

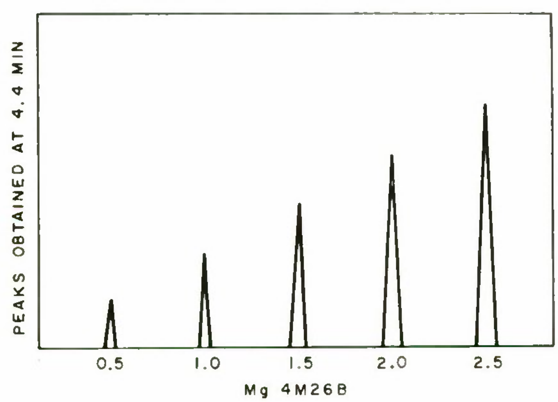

FIG. 6. Calibration results GLC.

cyclohexane were added and the mixture was vigorously shaken for about five minutes.

The cyclohexane layer was forced into the neck of the flask by adding water and the flask was allowed to stand until separation was complete. About 5 ml. of separated layer were transferred to a sample bottle. 1 gm of sodium sulphate was added to remove traces of moisture. The cell was then filled and the spectrum region of interest was scanned. The peak height was measured at 2·8μ. For the calibration graph about 450 ml of aqueous methanol solution were added to each of six 500 ml volumetric flasks followed by 0·5, 1·0, 1·5, 2·0 and 2·5 mg of antioxidant. The calibration samples were then analysed following the above procedure. Calibration results are shown in Fig. 5.

Gas Liquid Chromatography

For the GLC method extraction of the aqueous methanol distillate with cyclohexane was done exactly as described for the IR determination.

A Perkin-Elmer Model 800 Chromatograph equipped with a flame ionisation detector was used for the analysis. The column consisted of a 5ft. $\times$ $\frac{1}{8}$in. o.d. copper coil packed with 5% SE-30 silicone gum rubber on 80/100 mesh Chromosorb P. The carrier gas was helium and the temperature program followed was from 130°C to 180°C at a rate of 10°C min. 3 μl of the cyclohexane layer containing the antioxidant were injected into the column. For the calibration graph 500 ml quantities of solutions containing 0·5, 1·0, 1·5, 2·0 and 2·5 mg 4M26B were made up as described in the IR method. Retention times for the cyclohexane and antioxidant were 1·5 and 4·4 minutes respectively. The calibration results are shown in Fig. 6.

Determination of Rust Inhibitor

The rust inhibitor selected for investigation was carboxylic acid ester, as it also is known to be contained in some turbine lubrication oils. Because of the low polarity of this type of additive and the molecular similarity to turbine oil, it is difficult to separate thoroughly. In addition the equilibrium $R_1COOR_2+H_2O \rightleftharpoons R_1COOH + R_2OH$ depends on many factors such as temperature, concentration, presence of catalyst, etc., making the direct determination of the ester impossible. To overcome this difficulty, the carbonyl group ($>C=O$) present in both ester and acid was determined. A pro-

TABLE I

(Results in mg/100 gm)

Sample No.	*Unit*	*Date*	*Anti-oxidant*			*Anti-rust*	
			TLC	*Colori-metric*	*IR*	*GLC*	*IR*
Unused oil	—	—	300	300	300	300	41
89	Port Turbo Blower	11 Sept./69	300				19
90	,,	14 ,,	300				18
91	,,	17 ,,	300				18
92	,,	20 ,,	300				32
93	,,	23 ,,	300				14
94	,,	29 ,,	300				14
95	,,	5 Oct./69	300				18
96	,,	29 Sept./69	280	280			21
209	,,	17 Dec./69	260	260			23
210	,,	17 ,,	290	290			23
103	Stbd. Turbo Blower	11 Sept./69	300				22
104	,,	14 ,,	300				32
105	,,	17 ,,	300				33
106	,,	20 ,,	300				23
107	,,	23 Sept./69	300				20
108	,,	29 ,,	300				24
109	,,	2 Oct./71	300	300			40
110	,,	12 ,,	240	240			35
110B	Main Engine Coalescer	2 Sept./69	300				41
156	,,	11 Oct./69	300				41
206	,, entry	24 Nov./69	300				40
205	,, exit	24 ,,	300				39
204	,, entry	1 Dec./69	300				32
203	,, exit	1 ,,	300				39
202	,, entry	8 ,,	300				38
201	,, exit	8 ,,	270	270			41
207	,, entry	17 ,,	220	220			34
208	,, exit	17 ,,	260	260			32

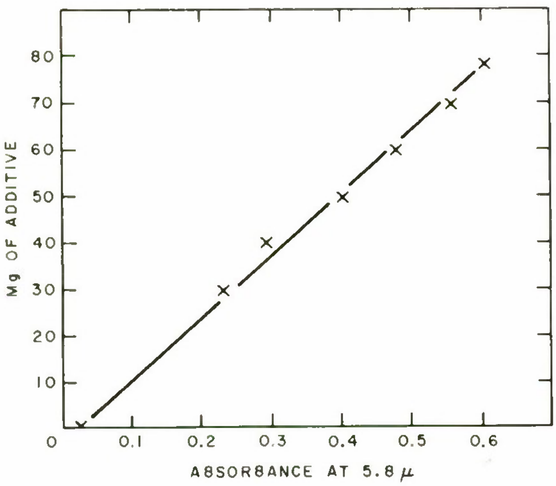

FIG. 7. Calibration graph.

cedure based on IR Spectroscopy[4] after partial separation of the additive with ethanol was successfully used.

Procedure Fifty ml. of ethanol were added to 100 gm. turbine oil in a 250 ml. conical flask and shaken for 10 minutes in a wrist-action shaker. The ethanol layer was transferred to a 100 ml conical flask, the solvent evaporated by heating to 130°C in an oil bath and the residue dissolved in 1 ml of CCl_4. The resulting solution was transferred to a NaCl cell with a fixed path length of 0·1 mm. The absorbance was measured at 5·8μ in a Perkin-Elmer Model 221 IR Spectrophotometer.

A calibration curve was prepared by adding 0, 30, 40, 50, 60, 70 mgm. increments of carboxylic acid ester to 100 gm. quantities of additive free base stock oil. The above procedure was followed and the absorbance measured at 5·8μ. The calibration curve is shown in Fig. 7.

Results The above procedures were followed in the analysis of turbine oil samples received from a Canadian naval vessel by the Dockyard Laboratory as part of a broader investigation of the serviceability of turbine lubricating oils that was being carried out. Results are shown in Table I.

The results show that there was no serious depletion of antioxidant during the service life of the oil from the time it was added until it was tested. The actual hours of service were not known but some samples would represent oils that were in use for at least several months. The oils in this service are not normally changed but topped up as required.

When compared with the unused oil sample, results for the anti-rust inhibitor show that for the Main Engine Coalescer there was no serious depletion. For the Port Turbo Blower, however, marked depletion (as much as 66%) was noted. For the Starboard Turbo Blower similar depletion (about 50%) had occurred. A possible reason for the depletion of the anti-rust inhibitor in the turbo blowers and associated coalescer could be water contamination that frequently occurs in the oil in these units.

Conclusions For the analysis of used turbine oils for antioxidant additive TLC affords the basis for a good semi-quantitative (±20%) procedure. It has the advantage that several samples may be run simultaneously. Either of the three instrumental methods described above is satisfactory. Repeatability is very good for all methods. Circumstances will suggest the choice of method. If the identity of the additives is in doubt, IR is to be preferred as this will give a positive identification as well as a quantitative result. The technique is somewhat more painstaking and if it is known that 4M26B is the only phenolic compound present the colorimetric or GLC method may best be selected.

For the determination of the anti-rust additive the procedure described above gives satisfactory results.

It is recommended that for future work the procedure for taking samples be standardized. Additional useful information would likely be obtained if a coalescer were set up in a laboratory to operate with a closed lubrication system and the oil analyzed periodically after an appropriate number of working hours. Possibly to simulate operating conditions water containing the equivalent contaminants should be added to the turbine oil.

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PIEZOELECTRIC TRANSDUCER MATERIALS

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Douglas Luff joined the RNSS in 1949 and worked for a number of years on the plastic deformation of metals. He obtained an external B.Sc. degree from the University of London in 1953 and undertook work on soft magnet ferrite from 1954 to 1958. In 1958 he began work on ferroelectric ceramics and is currently interested in the properties and applications of ferroelectric materials.

Introduction A transducer may be defined as a device which converts energy from one form into another. Under this definition electric motors and generators, internal combustion engines, batteries and many other devices could be classified as transducers. However, the term transducer is generally reserved for devices which convert electrical to mechanical or mechanical to electrical energy using some physical property of a material such as the piezoelectric or magnetostrictive effects. By far the most important group of electro-mechanical transducer materials are those which show piezoelectric properties, although materials showing closely analagous magneto-strictive properties have also been used for device applications.

Many crystalline substances show significant changes in dimensions when subjected to an electric or magnetic field, and conversely many materials may also be used to produce an electric signal when subjected to mechanical stress (Fig. 1). These effects are used in electro-mechanical transducers to convert electrical into mechanical and mechanical into electrical energy. In all but one of the non-centrosym-metric crystal classes mechanical stress produces a change in the dielectric displacement, called the piezoelectric effect, which may be used to generate an electric signal. The converse effect, the production of a strain by an electric field, is also found and is in fact more general since it is observed in all crystalline substances. The general equation for the strain produced in a crystal by an electric field is given by

SYMBOLS

<table>
<tr><td>E electric field</td><td>T mechanical stress</td><td>S strain</td></tr>
<tr><td>D dielectric displacement</td><td>P polarization</td><td>N Newtons</td></tr>
<tr><td>tan δ dissipation factor</td><td>C coulombs</td><td>F farads</td></tr>
<tr><td>V volts</td><td>m metres</td><td>Units MKS</td></tr>
<tr><td>s^E compliance at constant field</td><td colspan="2">k electromechanical coupling factor</td></tr>
<tr><td>Q_E electrical quality factor</td><td colspan="2">Q_M mechanical quality factor</td></tr>
<tr><td>R_M equivalent series resistance</td><td colspan="2" rowspan="2">T_C Curie temperature</td></tr>
<tr><td>L_M equivalent series inductance</td></tr>
<tr><td colspan="3">C_0 equivalent parallel capacity, clamped capacity</td></tr>
<tr><td colspan="3">C_M equivalent series capacity, motional capacity</td></tr>
<tr><td colspan="3">ε^T dielectric constant at constant stress</td></tr>
<tr><td colspan="3">ε^S dielectric constant at constant strain</td></tr>
<tr><td colspan="3">ε_0 dielectric constant of free space</td></tr>
<tr><td colspan="3">g piezoelectric coefficient, electric field/stress at constant field, strain/charge density at constant stress.</td></tr>
<tr><td colspan="3">d piezoelectric coefficient, strain/field at constant stress, charge density/stress at constant field.</td></tr>
</table>

$$S = dE + qE^2 \qquad \ldots (1)$$

where S is the strain, E is the electric field and d and q are material constants. In non-centrosymmetric piezoelectric crystals

$$dE >> qE^2$$

so that

$$S = dE \qquad \ldots (2)$$

In centrosymmetric crystals

$$d = O$$

so that

$$S = qE^2 \qquad \ldots (3)$$

Many authors have referred to the phenomena described by equations (2) and (3) as electrostrictive effects. However, it is perhaps more convenient to distinguish between them by referring to the phenomena described by equations (2) and (3) as the converse piezoelectric and electrostrictive effects respectively. Materials can then be divided into two groups, those having piezoelectric, and converse piezoelectric properties, and those having only electrostrictive properties. In principle, electrostrictive materials could be used for electrical to mechanical energy conversion, but in practice the electrostrictive effect is too small to be considered for device application.

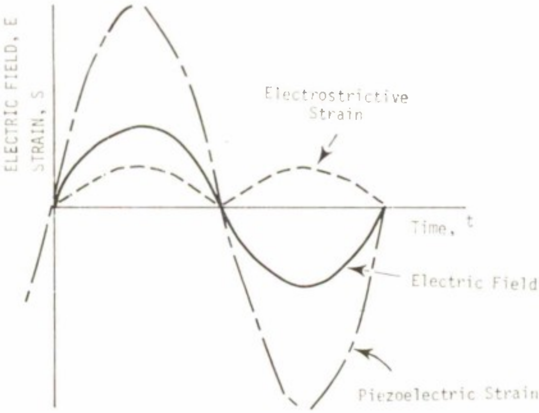

FIG. 1. The variation of strain with electric field for piezoelectric and electrostrictive materials.

Many magnetic materials change their dimensions in an applied magnetic field. The phenomena is similar to the electrostrictive and converse piezoelectric effects and is in fact called magnetostriction. Piezoelectric materials are more widely used for transducer applications than magnetostrictive materials because of their high efficiency. Consequently the remainder of the chapter will be confined to piezoelectric transducer materials although it should be mentioned that recent developments in magnetostrictive[1] alloys offer the possibility of higher efficiency magnetostrictive transducers in the future.

Piezoelectric Crystals

Piezoelectric crystals generate electrical energy when subject to changes in mechanical stress and mechanical energy when subject to changes in electrical stress. Fig. 2 illustrates schematically the production of a potential, or a transient current, by a piezoelectric element subjected to an applied stress. Typically a force of 1 kg applied to a 1 cm cube of ammonium dihydrogen phosphate (ADP) can produce a potential of the order of 300 volts and 1 kg applied to a lead zirconate titanate (LZT) element can produce a charge release of $6 \cdot 10^{-9}$ coulombs. Fig. 2 also illustrates the strain produced by an applied field. Typically a strain of $4 \cdot 10^{-5}$ can be achieved by a field of 1 kv/cm applied to an LZT element. Even higher sensitivities can be achieved using biceramic strips where it is possible to achieve displacements of several mm with a potential of only a few hundred volts.

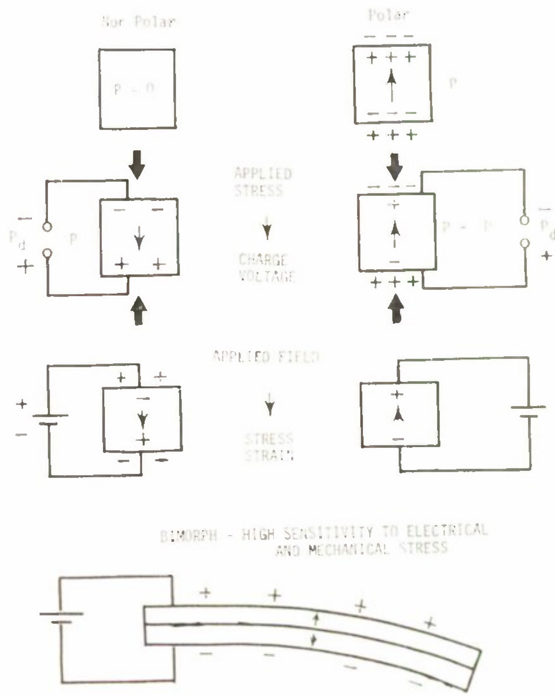

FIG. 2. The effect of electrical and mechanical stress on piezoelectric blocks and bimorph elements.

Piezoelectricity is dependent upon crystal symmetry. A centre of symmetry is a necessary, although not a sufficient, condition of piezoelectric activity, and of the 21 non-centrosymmetric crystal classes 20 are piezoelectric. Fig. 3 shows that piezoelectric crystals may be sub-divided into three types: non polar, polar ferroelectric and polar non-ferroelectric. In each unit cell of a polar crystal there is a net separation of positive and negative charge which may be represented as a dipole. These dipoles are aligned along preferred crystallographic axes, giving the crystals a spontaneous polarisation. The variation of the spontaneous polarisation with temperature, called the pyroelectric effect, can be used to produce an electric signal. Nonpolar piezoelectrics on the other hand have no spontaneous polarisation and show no pyroelectric properties. Finally, polar crystals may themselves be sub-divided into ferroelectric crystals, in which the spontaneous polarisation may be reversed by an electric field, and non-ferroelectric crystals in which the spontaneous polarisation is fixed.

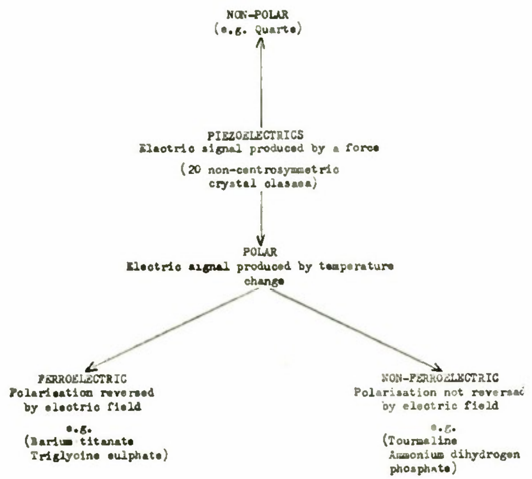

FIG. 3. The classification of piezoelectric crystals into three distinct types: (a) none polar, (b) polar ferroelectric and (c) polar none ferroelectric.

Piezoelectric Coefficients

The basic piezoelectric properties of crystals are given by the d and g coefficients which are defined as follows:

$$d = \frac{\text{Polarisation change}}{\text{applied stress}} = \frac{\text{charge release/unit area}}{\text{applied stress}} \ \text{C/N} \quad \ldots (4)$$

$$g = \frac{\text{electric field produced}}{\text{applied stress}} \ \text{V.m/N} \quad \ldots (5)$$

A second definition for d and g may be derived using the principle of superposition and the principle of conservation of energy. The dielectric displacement, D, and the strain, S, produced by a stress, T, at constant electric field is given by

$$S = s^E T \quad \ldots (6)$$

$$\text{and } D = dT \quad \ldots (7)$$

where s^E is the compliance at constant field and d is a piezoelectric coefficient. The dielectric displacement and strain produced by an electric field at constant stress are given by

$$S = d^1 E \quad \ldots (8)$$

$$\text{and } D = \varepsilon^T E \quad \ldots (9)$$

where ε^T is the dielectric constant at constant stress and d^1 is a piezoelectric coefficient. Using the principle of superposition the total strain and dielectric displacement is given by

$$S = s^E T + d^1 E \quad \ldots (10)$$

$$\text{and } D = dT + \varepsilon^T E \quad \ldots (11)$$

From the principle of conservation of energy the total energy stored in a crystal is the sum of the electrical and mechanical stored energy:

$$\tfrac{1}{2}\varepsilon^T E^2 = \tfrac{1}{2}S^2/s^E + \tfrac{1}{2}\varepsilon^S E^2 \quad \ldots (12)$$

where $S = d'E$ and ε^S is the clamped dielectric constant.

Equation (12) may be re-written

$$S^2/s^E = (\varepsilon^T - \varepsilon^S)E^2 \quad \ldots (13)$$

Now from (11)

$$\varepsilon^S E = -dT + \varepsilon^T E \quad \ldots (14)$$

where $T = S/s^E$ and using equations (8), (9) and (14) equation (13) becomes:

$$d = d^1 \quad \ldots (15)$$

Consequently d may also be expressed as

$$d = \frac{\text{strain produced}}{\text{applied electric field}} \ \text{m/v} \quad \ldots (16)$$

and by a similar argument

$$g = \frac{\text{strain produced}}{\text{applied charge/unit area}} \ \text{m}^2/\text{C} \quad \ldots (17)$$

The electromechanical coupling factor, k, gives a measure of the fraction of the stored energy which may be transferred from mechanical to electrical energy or *vice versa*. The coupling coefficient can be defined in terms of the other electrical parameters by considering the energies stored in a clamped and in an unclamped crystal. From equations (8), (14) and (15) the dielectric displacement in a clamped crystal is given by

$$\varepsilon^S E = \varepsilon^T E(1 - d^2/s^E \varepsilon^T) \quad \ldots (18)$$

The energy of the clamped crystal is then given by

$$\tfrac{1}{2}\,\varepsilon^S E^2 = \tfrac{1}{2}\varepsilon^T E^2(1 - d^2/s^E \varepsilon^T) \quad \ldots (19)$$

$$= \tfrac{1}{2}\varepsilon^T E^2(1 - k^2) \quad \ldots (20)$$

where $k^2 = d^2/s^E \varepsilon^T$

$$\therefore \quad k^2 = \frac{\tfrac{1}{2}\varepsilon^T E^2 - \tfrac{1}{2}\varepsilon^S E^2}{\tfrac{1}{2}\varepsilon^T E^2} \quad \ldots (21)$$

$$\textit{i.e. } k^2 = \frac{\text{(total energy stored in a free crystal)} - \text{(total energy stored in a clamped crystal)}}{\text{total energy stored in a free crystal}}$$

$$k^2 = \frac{\text{mechanical energy stored in a free crystal}}{\text{total energy stored in a free crystal}}$$

or in the general case

$$k^2 = \frac{\text{transduced energy stored in a free crystal}}{\text{total energy stored in a free crystal}} \quad \ldots (22)$$

The coupling coefficient, and hence the piezoelectric d and g coefficients, can be obtained by measuring the frequencies of maximum and minimum impedance for a piezoelectric disc, *i.e.* the resonance and anti-resonance frequencies. The equivalent circuit for a piezoelectric disc is given in Fig. 4. From equation (21) the coupling coefficient is given by

$$k^2 = \frac{\frac{1}{2}C_m V^2}{\frac{1}{2}C_m V^2 + \frac{1}{2}C_o V^2} \quad \ldots (23)$$

where C_m and C_o are the motional capacity and the clamped capacity of a piezoelectric element as defined in Fig. 4. In the equivalent electrical circuit a maximum and minimum impedance occurs when

$$\omega_R{}^2 = \frac{1}{LC_m} = (2\pi f_R)^2 \text{ (resonance)} \quad \ldots (24)$$

$$\omega_A{}^2 = \frac{1}{LC_1} = (2\pi f_A)^2 \text{ (antiresonance)} \quad \ldots (25)$$

where $1/C_1 = 1/C_m + 1/C_o$

$$\therefore f_R{}^2/f_A{}^2 = C_o/(C_m + C_o) \quad \ldots (26)$$

From (23) and (26)

$$k = \left\{1 - \left(f_R/f_A\right)^2\right\}^{\frac{1}{2}} \quad \ldots (27)$$

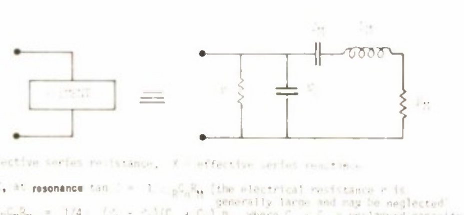

FIG. 4. The equivalent electrical circuit for a vibrating piezoelectric element.

N.B. A number of definitions of k in terms of f_R and f_A have been used in the literature and therefore care must be exercised in comparing k values from different sources.

There are in fact a number of d, g and k coefficients depending upon the crystal axes and the type of stress or strain. A matrix showing the d coefficient can be written:—

$$\begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \end{bmatrix},$$

and equivalent matrices can also be written for g and k. The first subscript denotes the direction of the electric field and the second the stress or strain. Subscripts 1, 2 and 3 denote the directions x, y or z axes (see Fig. 5).

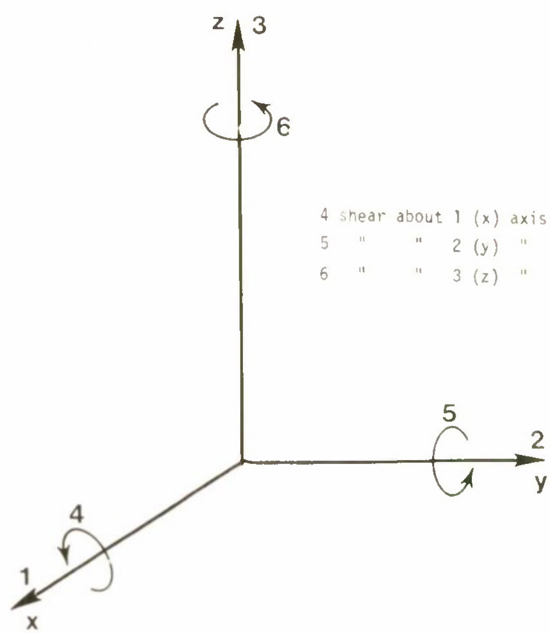

FIG. 5. The notation used to define the directions of the electrical and mechanical stress and strain in piezoelectric crystals.

For example:

$$d_{12} = \frac{\text{Strain produced in the 2(y) direction}}{\text{applied electric field in the 1(x) direction}}$$

$$\text{or} \quad = \frac{\text{Polarisation change in the 1(x) direction}}{\text{applied mechanical stress in the 2(y) direction}}$$

$$d_{26} = \frac{\text{Strain produced about the 3(z) direction}}{\text{applied electric field in the 2(y) direction}}$$

When an electric field, having components along the x, y and z directions is applied to a crystal there will be a total of 18 equations, corresponding to the 18 coefficients in the d matrix, giving the strains produced in the crystal. These equations written in the matrix notation become:

$$\begin{bmatrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{bmatrix} = \begin{bmatrix} E_1 & E_2 & E_3 \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \end{bmatrix}$$

The strains in the 1 direction may be obtained by the laws for matrix multiplication which say multiply the first row of the field matrix (and the only row) with the first column of the d matrix and add the products, *e.g.*

$$S_1 = E_1 d_{11} + E_2 d_{21} + E_3 d_{31} \qquad \ldots (30)$$

S_2 is obtained by multiplying the first row by the second column and adding the products, similarly S_3 is obtained from the first row and third column and so on. Certain of the coefficients in the d, g and k matrices may be zero depending on crystal symmetry, giving 20 matrix types[2] corresponding to the 20 piezoelectric crystal classes.

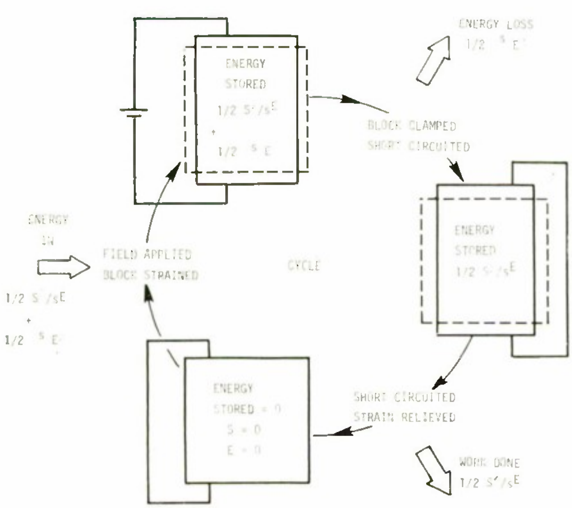

FIG. 6. A piezoelectric device converting electrical to mechanical energy.

Transducer Efficiency

Power dissipation in a transducer occurs as a result of electrical and mechanical losses. Electrical loss, shown in Fig. 4, occurs in the material and is expressed as a dissipation factor, $\tan \delta = R/X$, which is strongly field dependent. Mechanical losses occur in the material through 'molecular friction' and in the transducer itself through friction between moving elements. The mechanical losses are expressed as a mechanical quality factor,

$$Q_m = \frac{1}{\omega_R C_m R_m} \text{ as shown in Fig. 4.}$$

The efficiency of a transducer in converting electrical to acoustical energy will depend primarily on the electrical and mechanical losses defined above. However, in other electromechanical devices the efficiency is governed by the electromechanical coupling factor. This apparent anomaly can be resolved by considering a simple piezoelectric device in which electrical is converted to mechanical energy, shown in Fig. 6. The maximum efficiency in this case will be:

$$\frac{\text{Mechanical energy stored}}{\text{total electrical energy input}} = k^2$$

since the electrical component of the stored energy will be dissipated. The same efficiency would be achieved in an equivalent cycle converting mechanical to electrical energy (*e.g.* a spark igniter). Operating under a.c. conditions the situation is different since neither component of the stored energy will be dissipated as heat; energy is merely transferred between the effective capacitance and the effective inductance in the equivalent circuit. These a.c. devices only fail to reach 100% efficiency because of the dielectric and mechanical losses mentioned above.

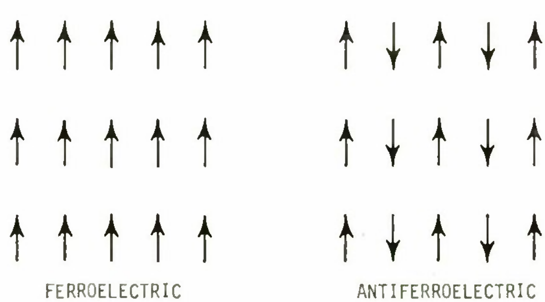

FIG. 7. The dipole arrangement in ferroelectric and antiferroelectric crystals.

Single Crystal Materials

Piezoelectric single crystals, whether ferroelectric or non-ferroelectric, need to be cut along preferred axes to produce usable elements, the cut generally being chosen to achieve maximum sensitivity. Until the development of ceramic materials, during the last two decades, single crystal materials were used in all piezoelectric transducer applications. The single crystal materials which had sufficient activity for device application included quartz[2, 3, 4] lithium sulphate[5] ammonium dihydrogen phosphate (ADP)[3, 5] potassium dihydrogen phosphate (KDP)[93] and sodium potassium tartrate (Rochelle salt) [2, 3, 5].

Non-ferroelectric single crystals

Non-ferroelectric single crystals, which may be polar (*e.g.* tourmaline, lithium sulphate and zinc sulphide) or non-polar (*e.g.* quartz and KDP), have in general, lower piezoelectric activity and lower values of dielectric constant and dielectric loss than ferroelectric crystals. Quartz in particular has a very low electromechanical coupling factor and dielectric constant, nevertheless it is the most commonly used single crystal material because of its strength, chemical stability and the stability of its properties with respect to time, temperature and electrical and mechanical stress[6]. Unlike many ferroelectric crystals quartz also retains its piezoelectric activity to relatively high temperatures, *i.e.* 550°C, where a phase transition occurs between the low temperature piezoelectric α and the high temperature β forms[2]. KDP, AKP and lithium sulphate have higher piezoelectric activity than quartz but are weaker mechanically, hydroscopic and also have low dissociation temperatures (see Table 1). Strictly, KDP should be regarded as a ferroelectric because it is transformed into a ferroelectric crystal below −150°C. ADP on the other hand, although structurally similar to KDP, is transformed into an antiferroelectric, rather than a ferroelectric, below −148°C. The antiferroelectric and ferroelectric dipole arrangements are compared in Fig. 7. The ferroelectric, or polar arrangement gives directional character and consequently piezoelectric properties to the lattice; the antiferroelectric arrangement does not. However, both KDP and ADP, like many crystals, are piezoelectric both above and below their transition temperatures[7], indicating that piezoelectric properties are not dependent on the ferroelectric or antiferroelectric state. Nevertheless, due to changes in crystal symmetry at the transition temperature, the nature of the piezoelectric activity will be changed. Strictly KDP should be classified as ferroelectric but, since it is ferroelectric only at very low temperatures, it is more convenient for present purposes for it to be classified as a non-ferroelectric.

Polar crystals of the wurtzite structure, *e.g.* ZnS and CdS[8], are similar in their properties to quartz. They have low piezoelectric activity, low dielectric constants and, unlike the water soluble crystals, they are stable to relatively high temperatures. Unlike quartz, however, the wurtzite crystals are polar and pyroelectric. ZnS (zinc blende) occurs naturally but it may be prepared, like other wurtzite compounds, by growing single crystals from the vapour phase. It is also possible, by evaporation and sputtering techniques, to prepare very thin sections of these compounds.

Ferroelectric single crystals

A ferroelectric may be defined as a polar crystal in which the direction of polarisation may be reversed by an electric field. It has been observed that ferroelectric, like ferromagnetic crystals, are divided into domain regions[3]. Within a domain the elementary dipoles in each unit cell are aligned along preferred crystallographic directions. A crystal, however, is generally divided into a number of domains whose moment, or polarisation, is oriented in different directions. Many ferroelectric, piezoelectric materials have high piezoelectric properties and high dielectric constants[7] but unfortunately they also usually have high dielectric losses and show considerable variation in their properties with time, temperature and applied electrical and mechanical stresses[7]. Domain boundary motion can contribute to the high dielectric and piezoelectric properties of ferroelectric crystals[6]. However, boundary motion is also thought to be responsible for the variation of the electrical properties with time[10], electrical[11] and mechanical[12] stresses and, at least in part, for the high dielectric losses [11].

Many ferroelectric crystals, *e.g.* those with the perovskite structure, have a distorted cubic lattice in which the polarisation may be oriented along [100] crystal directions. The resulting domain structure is shown in Fig. 7. In the virgin state most ferroelectrics, like magnetic crystals, have a random domain structure. The crystal, therefore, has no net polarisation and, in most cases, no piezoelectric activity. If a sufficiently high field is applied a net polarisation and piezoelectric activity can be induced. The effect of the field is to re-orientate the dipoles into the field direction. When the field is removed part of the induced polarisation, called the remanent polarisation, is retained due to a hysteresis effect. Ferroelectrics in fact display a hysteresis loop in an alternating field, see Fig. 8, which is analogous to the loops observed for magnetic materials. Clearly, in operation electric fields must always be much smaller than the coercive field to prevent the depolarisation of the crystal.

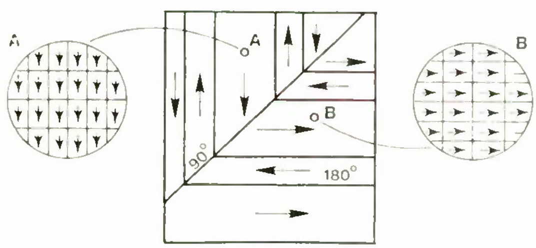

FIG. 8. The ferroelectric domain structure in compounds with the perovskite structure.

Above a certain critical temperature, called the Curie temperature, T_c, ferroelectrics lose their spontaneous polarisation, and in most cases, their piezoelectric activity. This process is reversible, on cooling back through the Curie temperature the spontaneous polarisation is recovered but the crystal will now have a random domain structure and will require to be re-polarised by an electric field (see Fig. 9) before piezoelectric activity is restored. Close to the Curie temperature the properties of a ferroelectric are considerably modified[7]. For example, the dielectric constant and the dielectric loss may increase by an order of magnitude while the polarisation and piezoelectric activity falls rapidly. Barium titanate and lead zirconate titanate, like most ferroelectrics, loose all piezoelectric activity above the Curie temperature due to the transformation from a non-centrosymmetric to a centrosymmetric structure. In contrast, a number of water soluble single crystals, such as Rochelle salt and KTP, are transformed from a noncentrosymmetric to a second noncentrosymmetric structure at the Curie temperature and in this case a loss of ferroelectric properties is not accompanied by a total loss of piezoelectric activity.

A large number of water soluble ferroelectrics can be readily and cheaply produced in the form of single crystals. Two of the most well known, Rochelle salt and triglycine sulphate, are widely used but these materials have the same limitations as the other non-ferroelectric, water soluble crystals, ADP and lithium sulphate. Rochelle salt shows very unusual behaviour in having two ' Curie ' temperatures, one at $-18°C$ the other at $+24°C$ [3]. Between these two temperatures the material is ferroelectric with very high piezoelectric activity[5, 6], and in this case very high dielectric constants are found at both the higher and lower Curie temperatures[3]. Above $24°C$ and below $-18°C$ the crystal is also piezoelectric but with lower activity[7].

The very large group of oxide ferroelectrics, in general, show transitions from a ferroelectric to a centrosymmetric, non-piezoelectric structure at the Curie temperature[3]. These oxide materials are mechanically strong, resistant to chemical attack, have high melting points and dissociation temperatures and, in many cases, high Curie points. Unfortunately the oxide ferroelectrics cannot be readily produced as single crystals. Relatively small crystals of a limited number of compounds have been produced[13] (for properties see Table I) but the quality, size and reproductibility would at present exclude them from consideration for transducer application.

Ceramics

The largest class of piezoelectrics in use today are the ferroelectric ceramic oxides. These materials combine the advantages of using strong, stable oxides at lower cost than the water soluble single crystals. Furthermore, since the ceramics can be made to any size and shape and do not require to be oriented along preferred crystal directions they offer greater versatility in element design.

A ceramic consists of a compact of very small crystals which, in the case of ferroelectric ceramics, have their axes oriented in different directions. The ceramic, like the single crystal, has no net polarisation in the virgin state and is required to be polarized

TABLE 1.

Material	Type	Direction: Field	Direction: Stress	k	d, C/N x 10^{+12}	g, Vm/N x 10^{+3}	ϵ^T/ϵ_o	Temp. °C Max. Op.	Comments
Quartz (SiO_2)	Non-Polar	1	1	0.10	2.3	58	14.5	550	Stable Commercially available
		1	2	0.10	2.3	58			
		1	4		0.7				
		3	3				4.7		
Ammonium Dihydrogen Phosphate (ADP)	Non-Polar	1	1				56	125	Hygroscopio Commercially available $\tan \delta_3 = 0.06$ $\tan \delta_3 = 0.07$
		1	4		1.5	3.1			
		3	3				1.5		
		3	6	0.36	48	350			
Potassium Dihydrogen Phosphate (KDP)	Non-Polar (*at RT)	1	1				46	150	Hygroscopic $\tan \delta_1 = 0.045$ $\tan \delta_3 = 0.070$
		1	4		3.6	3.3			
		3	3				21.3		
		3	6	0.13	21	116			
Tourmaline (Na, Li, K Silicate Borate)	Polar	1	1				6.3	Melts 900	
		1	5		3.6				
		2	2		0.3		6.3		
		3	1		0.3				
		3	3	0.10	1.9		7.1		
Cadmium Sulphide	Polar	1	1				9.3		
		1	5	0.19	14.2				
		3	1	0.12	5.2				
		3	3	0.26	10.3		10.3		
Zinc Sulphide	Polar	1	1				9.0		
		1	4	0.08	3.2				
		3	3	0.07					
Lithium Sulphate	Polar	2	2	0.36	16	175	10.3	Melts 75	Hygroscopic
Rochelle Salt (Na, K Tartrate)	Ferro-electric			24°C / 30°C	24°C / 30°C	24°C / 30°C	24°C / 30°C	45 Curie pts -18 +24	Hygroscopic, properties very temp. dependent Coercive field 20-50 V/cm
		1	1				3000 / 350		
		1	2	0.90 / 0.64					
		1	4	0.94 / 0.75	550 / 250	180 /			
		2	2				9.0 / 9.5		
		2	5	/ 0.32	54 /				
		3	3				9.0 / 10.0		
		3	6		12 /				
Triglycine Sulphate (TGS)	Ferro-electric	1	1				8.6	Curie pt +49	Hygroscopic, properties very temp. dependent Coercive field 40 V/cm
		1	4		150				
		2	2		20	150	43		
		3	3				5.7		
		3	6		550				
Lithium Niobate	Frozen Ferro-electric	1	1	Thickness 0.17 Shear 0.61			80	Curie pt 1210	Stable
		1	3		0.9				
		1	5		74				
		2	2		21		80		
		3	3		16	24	30		
Lithium Tantalate	Frozen Ferro-electric	1	1	Thickness 0.19 Shear 0.39			53	Curie pt 630	Stable
		1	5		26	56			
		2	2		8.5	18	53		
		3	3		9.2	24	44		

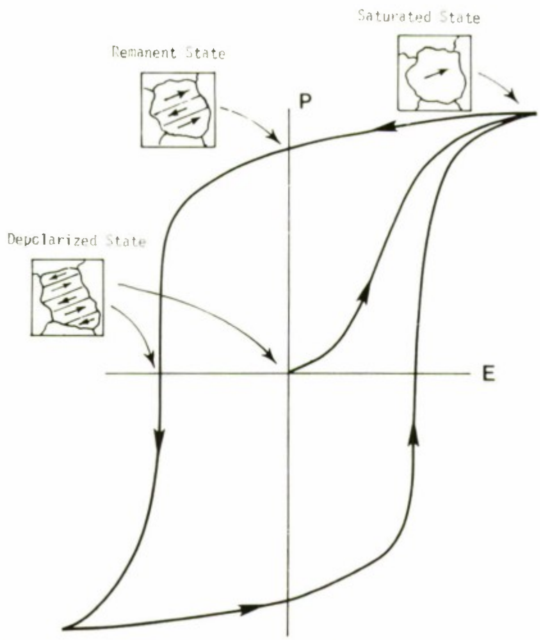

FIG. 9. The hysteresis loop for a ferroelectric ceramic showing domain reorientations occurring during a cycle.

to induce piezoelectric activity. The process of polarization in a ceramic is illustrated schematically in Fig. 9. Clearly the maximum polarization and piezoelectric activity will always be lower in a ceramic than in a single crystal, due to disorientation of the grains in the ceramic. However, disorientation is only one factor causing differences in the properties of ceramics and single crystals, the microscopic size of the grains in a ceramic is probably even more significant, particularly in explaining the very high coercivity of ceramics.

Barium titanate (BT)[6, 14, 15b, c] and lead zirconate titanate (LZT)[15] piezoelectric ceramics are widely used as electromechanical transducers. These names in fact refer to two families of materials whose properties may be modified by changes in chemical composition and preparation procedure. For example, LZT, which is a solid solution of lead zirconate and lead titanate, shows a considerable variation in properties as the ratio of LZ/LT is varied[15d, e, 16] (see Fig. 10). The maximum in the piezoelectric properties and the dielectric constant occurs at an LZ/LT ratio of $\approx$50/50. The partial replacement of Pb^{2+} by Sr^{2+}, Ba^{2+} and Ca^{2+} and doping with additives can also markedly affect the properties of the material (see Table 2)[17]. For example, the substitution of Pb^{2+} by Sr^{2+} increases the dielectric constant while the addition of small amounts of Nb_2O_5 increases the dielectric constant, the electromechanical coupling factor and the dielectric loss.

The Curie temperature of commercial BT and LZT ceramics is $\approx$ 120°C[6, 14] and $\approx$ 300°C[14, 15, 16] respectively. The maximum safe operating temperature, however, will be considerably lower. For example, 10% loss in k was observed after two hours at 200°C for an LZT ceramic with a Curie temperature of 300°C[18]. On the other hand strong piezoelectric properties can be retained to very low temperatures (−200°C[19]). Ferroelectrics have been reported with very much higher Curie temperatures[7], for example: lead metaniobate (550°C), lithium niobate (1200°C), lithium tantalate (700°C) and strontium barium niobate (550°C), but only lead metaniobate is at present available commercially in ceramic form.

Materiel	Direction: Field	Direction: Stress	k	d, C/N x 10^{+12}	g, Vm/N x 10^{+3}	ϵ^T/ϵ_0	Q_M	tan δ	Curie Temp °C
Barium Titanate	3	1	0.16	35	3		500	0.01	110
	3	3	0.37	52	5	1000			
	3	P	0.28						
Lead Zirconate Titanate Type 2	1	5	0.70	440	50		680	0.005	370
	3	1	0.23	60	15				
	3	3	0.63	150	38	450			
	3	P	0.47						
Type 4	1	5	0.71	500	39		500	0.014	330
	3	1	0.33	120	11				
	3	3	0.70	290	26	1300			
	3	P	0.58						
Type 5	1	5	0.67	740	27		65	0.02	190
	3	1	0.39	270	9				
	3	3	0.75	590	20	3400			
	3	P	0.65						
Lead Metaniobate	3	1		12			5	0.01	550
	3	3	0.40	75	35	240			

TABLE 2.

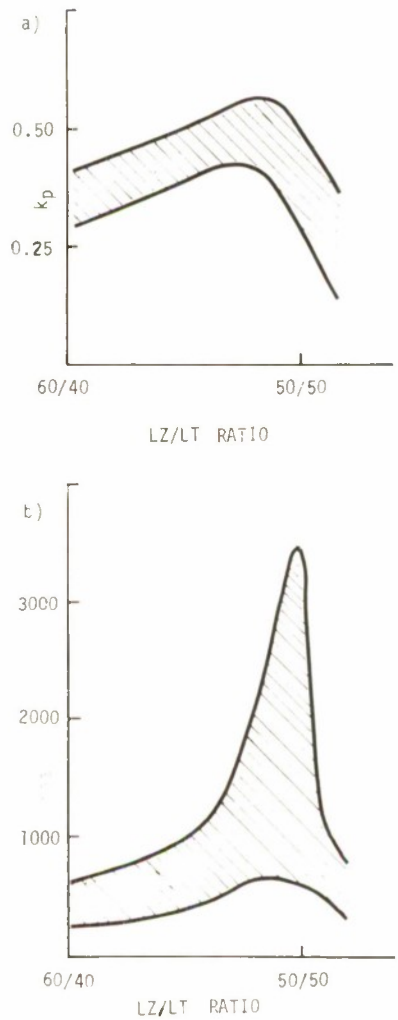

FIG. 10. The variation of the planar electromechanical coupling factor, k_p, and the dielectric constant, ε_{33}, with the ratio of lead zirconate to lead titanate.

The coercive field will also be a limitation in the operation of a material. Commercial LZT and BT ferroelectrics have coercive fields within the range 5 - 12 kv/cm[14, 15] and working fields must be lower (LZT 2kv/cm) to avoid serious degradation in the properties. Strictly, in ferroelectrics, polarization reversal is dominated by thermal activation so that polarization and depolarization depend not only on field but also on time and temperature[20]. In most cases the driving field is not limited by the coercive field but by the dielectric loss, tanδ[14] since at high fields serious heating problems may occur, which could lead to depolarization of the ceramic.

Another limitation of ferroelectrics is the depolarization caused by high mechanical stress. The various grades of LZT and BT show considerable differences in their ability to withstand stress. For example, it has been reported that a one dimensional stress of $7 \cdot 10^6$ kg/m^2 had little permanent effect on k for type 4 commercial materials but permanently reduced k for type 5 materials[21]. However, prolonged periods under stress and stress cycling can produce even more serious depolarization. Clearly if high temperatures, fields and stresses are applied simultaneously the limits for operation must be further restricted.

Applications

Piezoelectrics are used to produce and detect sonic and ultrasonic vibrations, to generate high voltages and in the production and processing of radio frequency signals. Ceramic materials are now used in most of these applications although quartz crystals are still favoured in most electronic applications where high stability is required.

Ultrasonic piezoelectric transducers are used in an increasing number of applications including sonar systems[22] where transducers, operating underwater at frequencies in the range 1 - 100 kHz are used to transmit pulses and receive the reflected echoes from solid objects and similarly in ultrasonic non-destructive testing[23] where signals, typically in the range 1 - 5 MHz are used to locate defects in solid objects. Ultrasonic transducers operating in air, in the frequency range 10 - 100 kHz, are used for monitoring devices[15a] and in this case flexure mode vibrations are used to achieve large displacement, necessary for good electroacoustic efficiency. The many other applications of ultrasonic transducers[22, 24, 25] include welding, soldering, machining, cleaning emulsification and accelerometers which are used to monitor vibrations in engines and other structures. High voltages produced by piezoelectrics are used for ignition[26] in gas appliances, petrol engines and for the detonation of explosives. In the electronic field piezoelectrics are used in delay lines[15a], filters[6, 15a], oscillators[6] and transformers[27].

Future Developments in Materials

Different applications of piezoelectrics invariably require particular combinations of electrical parameters. Ideally the properties of piezoelectric ceramics could be optimized by changes in composition and preparation procedure to suit the particular application. In practice a limited number of materials have been developed specifically for those applications where the demand is sufficiently high to make the development and production of a new brand economic. However, in many existing and proposed applications large improvements, which would not seem possible using LZT or BT, are required. For example, the following improvements are necessary:—

(1) higher piezoelectric coefficients,
(2) (a) higher dielectric constants (ε)—ignition,
(b) lower dielectric constants (ε)—NDT, delay lines,
(3) lower dielectric loss (tan δ),
(4) higher mechanical loss—NDT, low mechanical loss—delay lines,
(5) higher Curie temperature (T_c),
(6) smaller variations in properties with time, temperature and electrical and mechanical stresses,
(7) lower density and greater strength, particularly shock resistance,
(8) (a) high coercive fields (E_c)—high power transducers
(b) low coercive fields—high strain transducers, air transducers,
(9) low hysteresis effects.

Many ferroelectrics systems have been examined, either as single crystals or ceramics, which offer improvements over existing materials[7, 28]. Compounds with the ilmenite structure, and in particular the high Curie temperature materials $LiNbO_3$[29] and $LiTaO_3$[30] are one of the most promising groups being investigated. Work on single crystals has suggested that these materials are "frozen" ferroelectrics since the polarization cannot be reversed at room temperature due to the immobility of the domain boundaries. Consequently, these materials should be very stable with respect to time, temperature and electrical and mechanical stresses; they should have low dielectric loss and low hysteresis effects. If these compounds can be polarized as ceramics, and retain the relatively high piezoelectric properties of the single crystal, they will be an important step forward in the development of piezoelectrics.

During the past decade a new class of piezoelectrics have been reported called phase transition materials[31 - 33]. By operating a ferroelectric close to a phase boundary it is possible to produce electrical and mechanical stress induced phase transitions. When the polarization and lattice dimensions of the phases differ significantly very high strains, voltages and charge release may be obtained, very much higher than that normally experienced in ferroelectrics. Unfortunately the transitions investigated show considerable hysteresis and are consequently very lossy processes which, at present, prevents them from being used in ultrasonic devices. Furthermore, the changes produced by mechanical stress are not reversible. The original polarized phase is converted by stress to a second phase which has a lower spontaneous polarization but the original phase is not recovered in a polarized form after the release of the stress. These materials can be used for applications, such as detonation, where the element is used only once to produce a large electric pulse or mechanical displacement. However, a very much wider application will be possible if materials can be developed which do not depolarize during cycling and which have much smaller hysteresis losses. For example, the large strains developed should enable phase transition materials to transmit energy into fluids more readily than is possible using conventional piezoelectrics.

Ferroelectric composite materials have been produced by supporting ferroelectric particles in a non-ferroelectric matrix[18, 34-36] such as a glass, rubber, wax or resin. These composite materials offer obvious advantages in fabricating unusual shapes, or thin sections and in the preparation of strong, low density materials. Some sacrifice in piezoelectric properties must be expected, however, other electrical properties may be improved.

Changes in the preparation techniques for ceramics could also lead to considerable improvements. For example, solution mixing to replace powder mixing[37, 38] and sintering under pressure[39, 40] are expected to affect the microstructure and consequently the electrical properties. Considerable improvement in the electro-mechanical coupling could be achieved by producing an oriented ceramic which would permit polar axes of the grains in a polarized ceramic to be completely aligned. This might be achieved by an electric field during pressing, similar to the use of a magnetic field during pressing of permanent magnet ferrites, or by electric, magnetic or mechanical stress at elevated temperatures.

A number of techniques offer the possibility of very thin piezoelectric sections which would permit the construction of ultrasonic transducers operating at very high frequencies (0·1 - 1GHz) and possibly allow the construction of thin film electronic components, *e.g.* delay lines, suitable for use in integrated circuits. For example, films of a piezoelectric material, CdS, have been produced by evaporation[41] and ferroelectric composite films have been prepared, using a ferroelectric powder held in an organic support, which could be applied by brushing[42] or silk screen printing. Even mechanical polishing has been adequate for the preparation of LZT ceramics down to 0·005 cm thick[43], which is sufficient to make them transparent, and using composites even thinner sections may be achieved.

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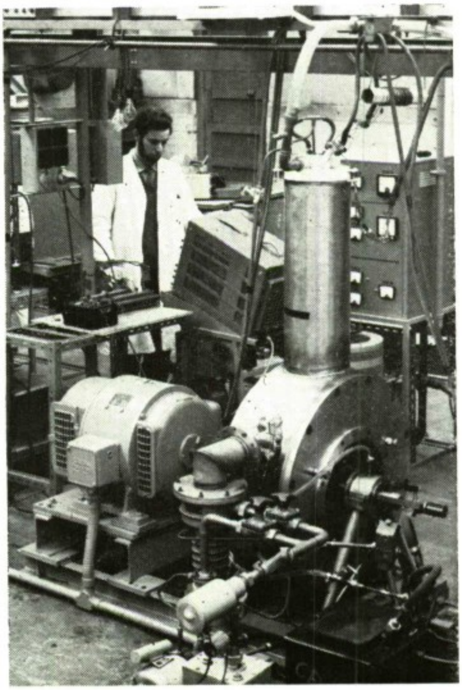
THE DEVELOPMENT OF SUPERCONDUCTING FIELD ELECTRICAL MACHINES BY MINISTRY OF DEFENCE

In the early 1960s there appeared to be reasonable prospects of DC power becoming available either from fuel cells or by direct conversion of nuclear heat thermo-electrically. Such power, if available, could not be utilised at that time in a practical ship propulsion system without resorting to gearing as low speed high power electrical machines, suitable for direct coupling to a propeller shaft, were heavy and bulky, and by using gears little advantage over conventional systems would be achieved.

Superconducting materials were beginning to show promise at that time and with the potentially high fields likely to accrue from their use, without an iron circuit, seemed to offer a substantial reduction in both weight and size of a low speed motor directly coupled to a propeller shaft.

In September 1963, therefore, after discussions with Messrs. International Research and Development Co. Ltd., a contract was placed by MOD(N) with the firm to examine the possibility of using superconducting materials for the field winding of a low speed engine. The study was to include review of the practical problems of refrigeration, heat leakage paths, including the shaft, magnetic shielding, etc.

This study was completed in September 1964 and it was clear from the report that the most promising machine would be of the homopolar type, *i.e.* a Faraday disc but some problems still required solution. The homo-



Model Superconducting Motor
Output: 50 h.p. at 2,000 r.p.m.

polar machine has a simple coil system, which is essential if it has to operate at about 4°K, and has an additional advantage in that there is no inductive coupling between the field winding and the rotor conductors, hence no torque reaction appears on the superconducting field coil. A major difficulty with this type of machine is in the current transfer to the rotor since, in its simplest form, there are effectively only two armature conductors and the working voltage is very low and correspondingly high currents are involved. This is why the homopolar machine invented by Faraday has not been exploited in the past. To solve this problem, liquid metal was proposed as a means of current transfer in the initial study, but further investigation showed that rubbing contacts using modern brush materials were practicable.

Although the available superconducting materials at that time were poor compared with those available today, it was decided to go ahead and build a model machine to prove the theories developed in the feasibility study and to demonstrate that such a machine was practicable.

Accordingly a second contract in the form of a research project was placed with Messrs. International Research & Development Co. Ltd. on 9.12.64 to design and build a small DC homopolar machine with a superconducting field coil. The superconductor was to be of stranded niobium zirconium suitably modified by IRD to provide stability and directly cooled by liquid helium. As this was a research project, a nominal output of 2 hp was stipulated in the contract and the design was to be arranged to reproduce dynamic similarity with a full scale motor, *i.e.* current ratings of brushes and rubbing speeds, optimum field strength, voltage, effects of adding iron to the field system, etc.

The motor ran for the first time on August 3rd, 1966 and developed 50 hp at 2000 r.p.m., amply demonstrating the feasibility of a small scale unit. It remained, however, to demonstrate the use of superconducting materials in a large economically viable machine and to this end the subject was passed to NRDC for further development.

After careful consideration, NRDC placed a contract for a 3,200 h.p. 200 r.p.m. unit, which subsequently became known as the "Fawley motor" since the Central Electricity Generating Board had kindly provided test facilities at their new Fawley Power Station. This machine has now completed its trials and so far as the machine and cryostat were concerned was remarkably close to a design performance.

With the completion of the model motor in 1966, a number of problems remained outstanding. For machines of this type to be applied to R.N. ship propulsion, it is necessary to

(a) be able to control the speed of the propeller shaft under manoeuvring conditions

(b) increase the operating voltage and thereby reduce the currents involved

(c) reduce the external field to NATO standards

(d) provide means of electrical protection under fault or damage conditions

(e) develop means of current transfer under high rubbing speeds when the prime mover is a turbine.

Apart from the higher voltage and fault protection, the Fawley motor did not cover these problems and considerable research has been involved in their solution. In particular, the source of DC power on board ship was lacking since the direct conversion hoped for in the early 1960s had not materialised and hence a DC generator with a superconducting field to provide this power was necessary.

To vary the speed of the main motor it is necessary either to change the field or armature current and if the prime source of power is a generator driven by a diesel or gas turbine, it is still necessary to change the field of the generator to control its output voltage, hence field control of the generator or motor, or both, is essential. With the early superconducting coils, rapid change of field current was impossible, but with the new forms of intrinsically stable conductor, the rate of change of the field necessary for manoeuvring a ship has been shown to be feasible.

The stage has now been reached therefore where a MOD(N) contract has been placed for the design and manufacture of a small diesel electric system comprising a superconducting field motor and generator which, subsequent to satisfactory short trials, will be fitted to one shaft of a small R.N. vessel of some 450 tons for sea trials.

ANGLO-AMERICAN GAS BEARING RESEARCH MEETING, U.S.A, 1971

Reported by A. G. Patterson, M.A., M.I.E.E., R.N.S.S.
Admiralty Compass Observatory

FIG. 1. British and American delegates at The Franklin Institute.

The fourth joint meeting of the Anglo-American Gas Bearing Groups was held at the Franklin Institute Research Laboratories, Philadelphia during April. The American Group is sponsored on behalf of U.S. Government organisations by the Office of Naval Research and the British Panel on behalf of the Ministry of Defence by the Admiralty Compass Observatory, Slough.

Two days of meetings took the form of informal presentations by British and American delegates on progress in various gas bearing projects in universities, government laboratories and industry in both countries.

Delegates travelled by R.A.F. from Brize Norton and on by local airline to Philadelphia. At the opening session they were welcomed by Mr. Nelson Droulard, Deputy Director at the Franklin. He was followed by Mr. Stan Doroff (ONR) Administrator of the American Group, who introduced Professor Dudley Fuller (Columbia University) as Chairman of the first day's sessions, and Mr. Henry J. Elwertowski (A.C.O.) who was to preside on the second day. Mr. Elwertoski responded on behalf of British delegates to the address of welcome.

Activities at the Franklin

The opening speaker was Mr. W. Shapiro (FIRL) who outlined some of the Lubrication Laboratory activities in gas bearings, particularly with the externally pressurised varieties having flexible mountings, various types of seals, porous bearings and types used in cryogenic machinery. A field of effort in which FIRL was particularly strong was in the provision or development of computer programs for many classes and varieties of bearing.

Forthcoming projects at the Franklin would include work on 30,000 RPM 1ft. diameter thrust bearings and on a 24,000 rpm turbo alternator/compressor for Brayton Cycle Space Vehicle work.

Mr. J. McCabe (FIRL) enlarged on some of these projects and on the analytical capability at the Institute, giving an example of a journal bearing analysis for cryogenic turbomachinery which cost only £1 in computer time.

Porous and Compliant Bearings

The first British contribution came from Dr. I. S. Donaldson (Queens University) who described experiments on porous insert externally pressurised thrust bearings, aimed ultimately at machine tool applications.

Next Mr. G. K. Rightmire (Columbia University, New York) outlined his work on a rig for pressure mapping under tilting pad bearings being followed by his colleague Mr. J. Pirvics who discussed the dynamics of compliant surface air bearings and emphasised their advantages in thrust applications.

Work of Mechanical Technology Inc., Albany, N.Y.

MTI is a commercial organisation devoted almost entirely to work on gas lubrication, both theoretical and experimental, and a summary of its activities was given next by Mr. O. Decker. In his talk, he described the application of gas bearings to an advanced 60,000 RPM, 750 HP gas turbine engine operating at temperatures up to 2000°F; the study of shock and vibration effects on bearings, particularly in space environments; lubrication by process steam using tilting pad externally pressurised bearings; gas bearings for helium circulators in reactors and some experimental investigations in the field of elastohydrodynamic lubrication. Mr. W. Waldron (MTI) then spokes about the material problems of the gas turbine engine bearings, reporting on the sliding properties, start/stop capability and bond strength of various coatings and the superior performance given by chrome oxide.

Bearing Materials and Manufacturing Methods

Mr. D. Young (Data Recording Instrument Co.) first gave an account of his current work on gas bearing flying heads for computer applications and followed this with a description of part of a gyro bearing materials study carried out for ACO while serving with the Sperry Company and which was concentrated upon a "short list" of ceramics including boron, carbide, chrome oxide, silicon nitride and several other hard non-metallic materials.

In a talk which blended fundamentals and engineering practice, Professor P. J. Gielisse (University of Rhode Island, Kingston) surveyed methods of machining ceramics, with particular reference to gas bearing components. He traced out various relationships such as that between grinding wheel surface hardness and wheel speed. He further considered the behaviour of single diamond points; carrying out thermal analyses of processes involved and taking account of heat flow in tool chips and workpiece, finally concluding that less damage resulted when working small grain-size materials.

On the same general theme, Mr. R. L. Stokes (Honeywell Research Center, Hopkins) explored more deeply into problems of grain pull-out and contamination related to crystal cleavage faces, slip planes and shear in such materials as aluminium oxide and boron carbide. By studying material removal rates against specific grinding energy, together with making an examination of surface topography, it was possible to identify surface conditions generated by brittle fracture, plastic flow or the exposure of internal structure.

Mr. K. A. Taylor/Draper Instrumentation Laboratory (formerly MIT) Cambridge Mass. described his recent work on sputter-etching processes to make loxodromic grooves on ceramic hemispherical gyro bearings, including the manufacture of metal masks for this process. Particular emphasis was paid to the study of the effects of workpiece orientation in placing components within the vacuum sputtering jar. In addition to sputter-etch removal of groove material, Mr. Taylor discussed his deposition experiments in coating gas bearing surfaces with tungsten carbide and chrome oxide.

In a British contribution, Mr. G. Beardmore (Smiths Industries) described his company's new rate gyro, using a rotor assembly of boron carbide. A particular feature of the project was the semi-production approach being made to the manufacture of this unit, which was expected to result in considerable cost reduction. Groove machining problems had been overcome by sputter etching and performance figures hitherto were impressive.

Another gas bearing gyro theme was discussed by Mr. A. G. Patterson (ACO Slough) who outlined a cost-reduction-study project in the manufacture of spiral groove thrust bearings. He indicated that work so far showed that considerably simplified and time saving methods and equipment could be used without degradation of performance, and that the traditionally rectangular groove shape was not paramount.

Steam, Foil, EP and Hybrid Bearings, Stability Studies, Analysis and Applications

In the field of steam bearings Dr. A. Duckworth (City University) gave an account of his experiments on slot-fed externally pressurised types, leading to design data. His work had demonstrated the advantages of slot-feed over orifice/pocket fed bearings, particularly in their freedom from self-excited steam hammer instabilities. An incidental to his talk was the coining of a new " SI " load unit of " 1 Apple ", presumably the magnitude exerted when the fruit was in contact with Sir Isaac's head!

Dr. Gu (MTI Albany) presented an analysis of the dynamic stability of gimbal bearings supporting a gas thrust bearing, deriving stability charts and showing how improved stabilisation could be obtained by damping.

A project for NASA was described by Professor E. J. Gunter (University of Virginia, Charlottesville), who reported on his work to obtain faster computation programs to predict behaviours of multi-lobe tilting-pad bearings lubricated either by oil or gas.

The growing interest in the U.S.A. in self-acting and externally pressurised foil bearings was reflected in a presentation by Dr. P. A. Szego (Ampex, Redwood City), who gave a preview of a forthcoming design manual for bearings of this class which should prove of value to those interested in potential applications of foils in computer and magnetic tapes.

Mr. D. A. Jones (Leeds University) aroused considerable interest when he showed part of his Fluid Film Bearing video tape, produced for educational use at Leeds.

The Gas Bearing Design and Advisory Service operated by Southampton University was the topic of Mr. R. W. Woolley, who outlined several interesting gas bearing case histories which the Service had handled recently. The first was the performance of a twin vibrator rig suggested by Dr. H. Marsh of Cambridge University and sponsored by ACO which could give non-destructive stability prediction for a wide range of journal bearings. A project for the University of Nottingham involved the development of a quarter-inch diameter rotor in a foil bearing, being driven at speeds approaching 900,000 RPM in helum gas. For the British Aluminium Co. an externally pressurised bearing system was developed in connection with continuous tensile monitoring of aluminium strip under severe environmental conditions. The rotor rollers were about 12 cm in diameter and 10 cm wide assembled on a shaft 1·2 metres long. A fourth project was to develop externally pressurised bearings to give virtually frictionless support to a three-ton plenum chamber used by Rolls Royce for work on air supply to jet engines.

Mr. P. A. McKeown (Cranfield Unit of Precision Engineering) gave an account of his Unit's work on instruments and machines using gas bearings, singling out some examples. A rotary table for the Horstmann Gear Co. on pressurised slot bearings for speeds 1/3 to 1/5 earth rate with digital read out was accurate to $1\frac{1}{2}$ sec. arc. A stellar interferometer on air bearings had been built for the Edinburgh Royal Observatory. An automatic measuring machine for the Rank Organisation was accurate to 1/10000″ and was used for quality control of T/V zoom lenses. Also in optics, an air bearing lens system developed for stellar galaxy work had operated continuously for $2\frac{1}{2}$ years and a high accuracy lens centring table had been developed for SIRA, accurate to 10 microinches. For ACO/DRI a high precision surface grinding machine was being developed to make better gas bearing components more cheaply, which itself would use air bearings in wheelhead, workhead and slideways.

Mr. D. D. Cooke (Royal Aircraft Establishment) made an assessment of the relative merits of hemispherical conical and spool configurations for gas bearing gyros, finally concluding that the conical form was to be preferred.

In a further presentation from the Franklin Institute, Dr. M. McReddi described his work on finite element analysis, directed towards design in such applications as computer flying heads.

Mr. J. Kerr (National Engineering Laboratory) illustrated by block diagram some proposals to co-ordinate the functions of bearing analysis, design and geometry optimisation with other variables, making special reference to computer graphics and their value in rapid and effective design. Among other NEL projects described were pressurised porous bearings on compliant surfaces for heavy load movement, pressure fed orifices on compliant surfaces for tracked vehicles, self-pressurised bearings for gas central heating fans and, in the field of medicine, slide bearing tables for heart performance study and cardiographic assessment of foetal distress.

A contribution from Mr. D. W. Geiling (Hamilton Standard Corp, Farmington) examined the significance of gas mean free path in gyro bearings, giving curves for helium, neon and hydrogen and concluding that significant effects on performance would only occur at low ambient pressures with small clearances.

Professor R. A. Burton (North West University Evanston) described his studies of the relationships between wear, frictional heating, expansion, temperature rise and load concentration,all relevant to solids in rubbing contact, and which commonly occurred in grinding operations as well as in gas bearings touching down at speed.

Professor H. G. Elrod (Columbia University, New York) discussed the surface phenomena of Reynolds roughness and Stokes roughness and their effects on gas bearing performance under compressible conditions. A report on this topic would be issued shortly.

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The next British contribution was from Mr. T. Kilmister (Southampton University) whose subject was the improvement of stiffness and load capacity of externally pressurised thrust bearings in machine tool applications, particularly by use of a flow-restrictor system.

Mr. R. Kemp (Goulder Micron Ltd.) described some applications of pressurised air bearing spindles to metrology instruments, explaining how increased stiffness had permitted relaxation in machined surface finishes without performance degradation.

A Columbia University student, Mr. D. Sood, next summarised his current analytical work on inertia effects which occur in foil bearings of types which may be used in magnetic tapes, illustrating his findings by pressure distribution curves.

Finally from Britain, Mr. C. Dee (Aerostatic Ltd.), traced the progression in pressurised gas bearings from orifice to slot configurations, outlining the advantages of the latter and showing photographs of such bearings which could directly replace rolling element varieties.

Tour of the Franklin Institute Laboratories

Delegates were shown some of the laboratory work of FIRL lubrication department, which included various instrumental rigs for gas and oil bearing theory validation at speeds up to 20,000 RPM. One of these included an environmental tank in which many ambient conditions of pressure, temperature and atmosphere could be simulated. In addition there was demonstrated cryogenic machine bearings for opration up to 200,000 RPM, journal bearing test rigs and systems for examining rolling and sliding contacts.

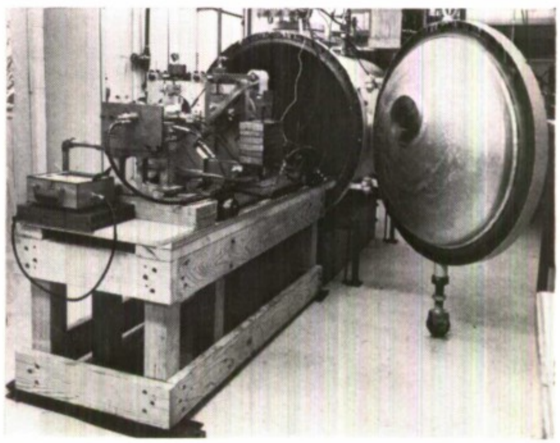

FIG. 2. Franklin Institute. Instrumented Gas Bearing Test Rig and Climatic chamber.

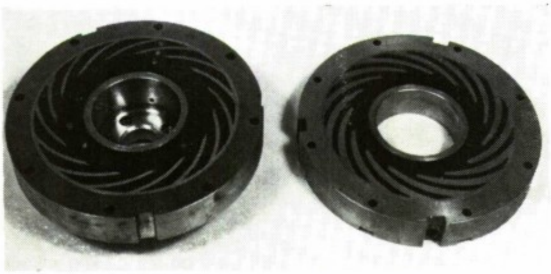

FIG. 3. M.T.I. Hybrid and Self-Acting Thrust Bearing.

Visit to NASA Lewis Research Laboratory, Cleveland

Most British delegates to the Franklin meetings were able to accept an invitation to visit NASA Lewis Lubrication Laboratory at Cleveland, which is engaged in a wide variety of tribological projects, both in the gas bearing field and in solid and liquid lubrication.

After a "red carpet" welcome from Mr. Manganelli, the Deputy Director, Mr. W. J. Anderson, head of the lubrication department and well known in Britain, summarised the activities of the Lewis Laboratory, particularly the work being undertaken in his own group. In the ensuing tour of projects, brief presentations were made by section leaders and apparatus was demonstrated and explained by the teams of specialist staff concerned.

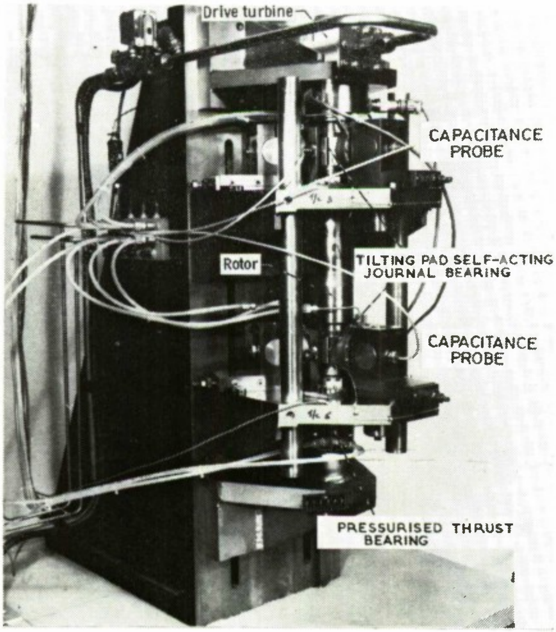

FIG. 4. N.A.S.A. Self-Acting Gas Journal and Pressurised Thrust Bearing on Test at 40,000 R.P.M.

The wide range of NASA interests covered included self-acting and externally pressurised air bearings, herring-bone journals, solid lubricants, rolling element bearings, seals, liquid metal bearings, water lubrication, electron diffraction studies of surfaces, sputter deposition and a study of bearing materials.

A final highlight of the Lewis visit was an inspection of NASA's Zero G Facility, capable of providing 10 seconds of weightlessness for experimental rigs weighing up to 6000lb. This is done by projecting the package upwards from the bottom of a 500ft. deep, 28ft. diameter shaft and then allowing a free-fall return. Final deceleration is achieved by dropping into 20ft. of expanded polystyrene pellets, whose frictional drag with the package absorbs its kinetic energy.

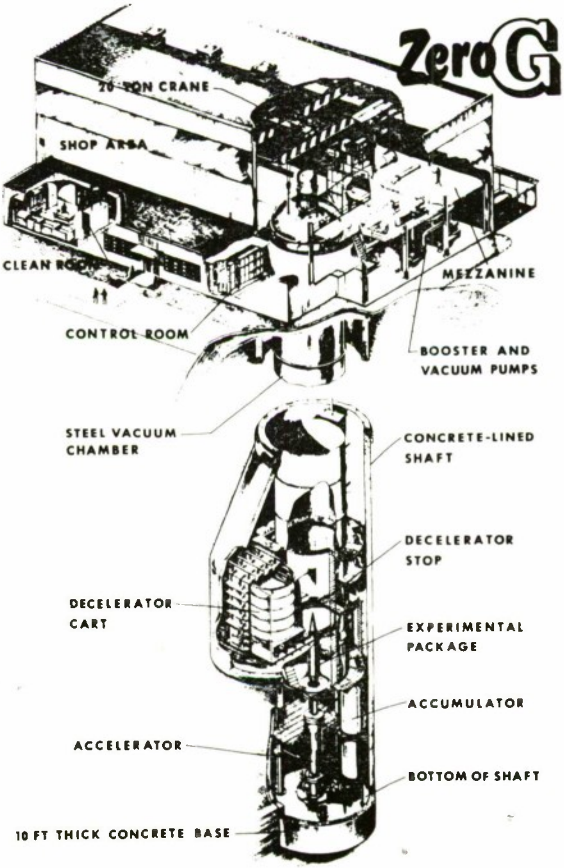

FIG. 5. N.A.S.A. schematic of zero G. test facility.

Visit to Mechanical Technology Inc., Albany, N.Y.

MTI is a leading U.S. Government contractor in the field of gas bearings, being particularly strong in analytical capability. Most of the British delegates were able to accept an invitation to see some of the projects currently in progress.

Following a welcome from Dr. D. Wilcox, who explained the organisation and activities of MTI, Dr. R. Coleman summarised his analytical work on gas bearing gyro behaviour under high G conditions axially, considering in particular the edge effects, pressure profiles and groove numbers in spiral groove thrust bearings.

Dr. R. Badgley then gave an account of progress in the design, building and test for NASA of a turbo generator which would serve as a 10 KW auxiliary power unit for a space station or shuttle. It would incorporate spiral grooved thrust bearings and tilting pad journal bearings for its 15 inch long shaft. A major problem encountered was bearing material selection to survive high speed touchdown.

Another project, for the U.S. Army and described by Mr. W. Waldron was a bearing assembly for a small jet turboshaft helicopter engine. Tilting pad journal bearings and spiral groove thrusts were being used, with a rotor weighing 24lb. Dynamic loads reached 150lb., temperatures rose to 650°F and speeds to 22,000 RPM.

In Elastohydrodynamic lubrication, Mr. J. McGrew demonstrated equipment for the study of torque as a function of slip rate in a rolling disc machine. One interest was to develop computer techniques to predict behaviour. Asperity count and film thickness measurements were being made for a polyphenyl ether lubricant.

Other projects described or demonstrated included steam bearings, compressors using self-acting bearings and operating up to 52,000 RPM, fast breeder-reactor liquid metal bearings and a performance appraisal of aircraft jet engine thrust bearings.

Future Programme

The Philadelphia meetings together with the associated visits to MTI and NASA provided another valuable Anglo American information inter-change in the field of gas bearings. To some British delegates it underlined the present omission in the U.K. to explore and exploit more of the potential applications of gas lubrication. " Lab-floor " discussions between transatlantic opposite numbers have proved to be of great mutual technical benefit, supplementing and sometimes exceeding in value the more formal exchanges at symposia and conferences of learned societies.

It is planned to continue the MOD(N)/ONR series of gas bearing meetings in April 1972 when the venue will be switched from the Penn county of the U.S.A. to the Penn county of Buckinghamshire.

ADMIRALTY SURFACE WEAPONS ESTABLISHMENT OPEN DAYS

Reported by B. C. Dodge, F.R.S.A., A.I.Inf.Sc,. R.N.S.S.
Naval Scientific Technical Information Centre

The Director and Sir Julian Amery at the Introductory Exhibit.

Introductory Display.
H.M.S. *Bristol* and A.S.W.E. activities.

During the week commencing 28th June, 1971, ASWE held Open Days when the Press, VIPs, including Earl Mountbatten of Burma and Sir Alec Rose, members of the Diplomatic Service, Industry and the general public, in all some 12,000 visitors toured the display and showed great interest in the work being undertaken.

Visitors were first directed to the Introductory Exhibit which, by a map and photographs, illustrated the present and future roles of the Royal Navy and the part played by ASWE and ACO in ensuring that the roles are achieved. The centre piece depicted weapons, communications and radar systems fitted in D-Type 42 destroyers and indicated other main themes exhibited in greater detail elsewhere. Illustrations showed the various ways in which the feasibility of fulfilling future defence needs were studied and methods used for estimating the performance of the weapons systems prior to their construction. Visitors were able to set the controls of a missile firing system and watch the track of the missile in flight displayed on a cathode ray screen.

Under the weapons systems section there were displays showing various types of radar used for surveillance, target indication, weapon control and navigation. These included a precision short/medium range radar for pilotage and seeking targets which was installed to show the shipping passing to and fro in the Solent. The high power, long range 3-D radar for directing fighters from aircraft carriers was operating to show aircraft flying over the Southern Counties and approaching London Airport.

" Electronic warfare " has been developed since the last war and naval operations have been increasingly dependent upon electronics for communications, weapon control and navigation. This is an " attack " of such systems and its purpose is to gain maximum military advantage from enemy transmissions, to spoil the value of these transmissions and at the same time protect our systems from enemy interference. One aspect of this type of operation was demonstrated showing how enemy transmissions are used to their disadvantage by providing a basis for their detection.

A SEASLUG and a SEACAT missile, as fitted in County Class Destroyers, were on display. The aerials of the radar systems which guide SEASLUG were shown on a rolling platform simulating the motion of the ship and the visitor could see the operations "acquiring" and "tracking" any aircraft in the vicinity. The results of experiments to automate part of the SEACAT guidance system were also exhibited. A model of H.M.S. *Bristol* showed SEADART and the integrated systems fitted in her and in ships of the type 42 class. An animated display also showed the steps in the engagement of an enemy aircraft by SEADART. Model radar and missile equipment were displayed, and also a working radar was in operation and a film of SEADART firings was shown. There were models of the aerials being used for the SEAWOLF automated guided missile which can be used with the computer-assisted action information system (CAAIS) and the radio-data link, both of which were exhibited.

Lord Louis Mountbatten and copper scale model ships used on the model antenna range.

The radio communications developed by ASWE are worldwide and operate between ships and from ship to shore. The visitor was shown the work undertaken by the Joint Radio Propagation Bureau in producing data and charts to ensure the best possible communication as conditions vary with sunspot activity, time of year and time of day. The satellite communication systems now being installed in ships uses a satellite as a repeater and employs radio frequencies which are not significantly affected by ionospheric conditions. Models of the units were displayed and live demonstrations in operation terminals showed how the system worked.

The difficulties of submarine communication were also explained, namely the need to design aerials to withstand the tremendous pressures when the submarine is submerged (this is done in conjunction with the Admiralty Materials Laboratory) and at the same time produce a retractable unit to reduce drag resistance.

Working mock-up of a S.S.N. wireless office.

Also displayed were the Decca navigation and the Loran system for coastal and ocean waters respectively. These systems enable the submarine to determine its position at any time and visitors were able to plot the positions indicated by the equipments on a special chart provided. The buoy which transmits a distress signal and flashing light and is used in an emergency was also shown. A life size replica of a submarine wireless office created considerable interest amongst the visitors.

ASWE's assistance to commercial shipping through the Department of Trade and Industry was also displayed. ASWE gives technical advice on navigational aids, evaluates equipments which have been developed commercially and seeks new forms of navigational aids for the mariner. These items include radar beacons which transmit an identification code when " illuminated " by ships radar and are invaluable in fog, radar reflectors for use by small craft make them more easily visible on ships radar screens and the collision avoidance computer created considerable public interest. This computer is used with radar to indicate a risk of collision and to help the navigator to decide on the best avoiding action by trying out different changes of course and seeing their effect before actually embarking on a change. The visitor was able to change the course and speed of " own ship " and see the effect of such action on the display.

Radar techniques naturally play an important part in the work at ASWE and the elimination of " clutter " makes the radar picture much clearer. Two remedial systems were shown both using the Doppler principle, one is the Moving Target Indicator and the other involves Pulse Doppler Techniques. A five centimetre experimental radar, a method of scanning electrically instead of mechanically and an automatic tracking technique whereby a computer records the position of aircraft as seen by the radar and then displays its path were also on view. The need for more equipment of greater complexity in smaller ships necessitates making them much smaller, more reliable and readily repairable. This has led to micro electronic techniques and liquid cooling power stages, examples of this type of equipment were on display.

The display by the Admiralty Compass Observatory showed that naval navigation extended far beyond the conventional direction-indicating and position-fixing of a ship being required to provide accurate positioning data and stabilization of the complicated and diverse weapons systems in a modern warship. In order to set the heading accuracy of the navigation system of Polaris Submarines an external heading reference is established and transferred by optical means to the submarine moored at the dockside. A shore-based theodolite provides the shore-to-ship optical link and an optical mast specially installed for the duration of the test provides an on-board vertical link to the navigation system. When at periscope depth the submarine can establish its position by taking sites of the sun and stars and measuring the elevation angles of these bodies with respect to the horizon, but since the natural horizon cannot always be clearly seen a gyro stabilized platform and mirror are used in conjunction with a level finding pendulum to provide an artificial horizon. The system operates with a sextant built into the periscope. the combined system being known as the Artificial Horizon Periscope Sextant.

Bearings for gyros have always presented problems and self suporting gas bearings have now been developed for the spin axis of gyros used in SINS and weapon stabilization applications. They contribute greatly increased accuracy to the former and increased life to the latter. Squeeze film technology being involved to provide improved forms of bearings for slow moving applications such as gymbals, and the visitor was able to see these in action.

Accurate and synchronized time displays have become necessary in recent years due to the reliance of ships on ships clocks to instigate daily routines. The system showed provided such a facility and has means of adjusting groups of clocks to coincide with local (zone) time and for correction of the GMT displays.

In order that magnetic navigation and direction devices may operate satisfactorily it is necessary that they be sited in a suitable environment free from interfering fields. A section of the Admiralty Compass Observatory is consultant to R A F., R.N., Army, M.A.S. and Department of Trade and Industry for assessing the suitability of sites in aircraft, ships and on land for the optimum performance of the magnetic centres, and also for the development of magnetic equipment. The gyro compass used normally as a navigational instrument is also used extensively to provide a stable reference for weapon systems. The Mark 23 compass gives asimuth stabilization only and is used for surface gunnery and torpedo systems. The more complex Mark 19 compass is also an accurate vertical seeking instrument and has wide applications as a three axis attitude reference for advanced weapons systems. Details of these were illustrated and three exhibits showed how the gyros, using gas bearings, are employed to stabilize ships guns, gunnery radars and to measure target speed and positions, for accurate gun aiming against air targets.

Also on view as part of the ACO display was the Ships Inertial Navigation System (SINS), ships movement over the earth, or more accurately movements in inertial space are detected by the gyroscope and accelerometer of SINS. These "inertial" centres are high precision instruments requiring the utmost care in design and manufacture. The gyroscopes currently used are of the single degree-of-freedom floated type, they are made chiefly of beryllium, a very light but strong material, and incorporate gas bearings of advanced design. The accelerometer is a two-axis, force-feedback pendulous instrument. Also on view was a demonstration of the basic principles of ring-lasers leading up to development models. The ring laser is a method of producing gyroscopic information by optical means in place of mechanical angular momentum.

Mention must also be made of H.M.S. *Grenville* which is one of the ships in which ASWE staff carry out trials of experimental and prototype equipment under the arduous conditions which are normally experienced at sea.

There can be no doubt that the ASWE Open Days were a great success and much of this success was due to the hard work put in by members of ASWE and also by the staff of the Manager Technical Illustrators Pool, who provided the professional expertise and kept a watching brief on all display matters.

CIVIL SERVICE COUNCIL FOR FURTHER EDUCATION

Up to last year the closing date by which applications for the Civil Service Further Education Prize Fund had to be received was September 30th. For 1971 and subsequent years the final date for receipt of applications will be *31st December*. Similar arrangements will apply for the literary and poetry competitions. A further change will be that the winners of the College Prize Fund, under which day release students are eligible for prizes, will be presented with their awards at the regional Further Education Prize Fund ceremonies. Application forms are available from your regional training officers or from the regional advisory officer covering the area in which your office is situated.

Another important aspect of the activities of the Council is its role as an Advisory Service for all civil servants. With the arrival of the 1971/72 academic year many of you may wish to enrol in a course of study ranging from academic subjects to the more liberal pursuits in the cultural or recreational fields. The Council's regional office staff are specially equipped to deal with any enquiries you may have.

NOTES AND NEWS

Admiralty Compass Observatory

Navigation Department of ASWE

A series of visits to ACO have been made by the Head of U.S. Polaris Project Office (SP 24) Washington and naval and civilian members of his staff. The primary purposes of these visits were to review British gyro developments and to discuss submarine navigational matters of mutual interest. A particular objective was to study experience gained with the heading transfer and alignment system developed by ACO.

The Controller of the Navy, Vice-Admiral Sir Anthony Griffin, K.C.B. visited ACO during May accompanied by the Director General of Weapons Rear-Admiral P. A. Watson, M.V.O., F.I.E.E., and senior members of their staffs. After discussions with members of ACO management, the party made a tour of inspection of laboratories and workshops and met senior members of ACO staff.

The British pioneering voyage of H.M.S. *Dreadnought* under the Arctic ice cap to the North Pole was made with the aid of her Mk. I SINS installation designed and developed at ACO. Mr. W. L. Thomson of the Observatory joined *Dreadnought* for the voyage to study the behaviour of SINS equipment, particularly at high latitudes.

Other equipment supplied by ACO for this special trip, to supplement the standard navigation outfit, included a Mk. XIX Gyro Compass, Loran C and Omega receivers for radio navigation together with an Arma Brown battery-backed gyro compass.

The 33rd meeting of the Inter-Service Gyro Panel was held at ACO in June and attended by representatives of Government establishments interested in gyros. Reports were presented by members of ACO and RAE on trials of American gyros undergoing evaluation at Slough and Farnborough respectively.

Mr. H. J. Elwertowski, Mr. E. Hoy and Mr. R. Weatherburn have visited the U.S.A. for discussions with U.S. Navy officials about the Omega project. They were particularly concerned with implementing installation schedules and Co-ordinating various activities. Omega is an international VLF Radio Navigation System, planned to give world-wide coverage by 1973.

The fourth joint meeting of the Anglo American Gas Bearing Group was held at the Franklin Institute Research Laboratories Philadelphia during April, the British group under ACO sponsorship travelling by R.A.F. from Brize Norton.

A full report on the meetings appears elsewhere in *J.R.N.S.S.*

Mr. J. Mayne, Head of Operational Research at the Canadian Ministry of Defence, Ottawa, visited ACO during May. In addition to a general tour covering R & D projects, Mr. Mayne had discussions on Magnetic Anomaly Detection equipment used in A/S warfare.

Following ACO's administrative incorporation with ASWE, a selection of 10 project displays from the Slough Establishment under the theme of " Navigation " were exhibited at Portsdown during the ASWE open days.

Favourable comment from many of the distinguished guests as well as from visitors from industry and the general public has given much encouragement to staff concerned.

Dr. Leonard Swern, Director of Technical Programming, Sperry Rand Inc., New York, visited ACO in July, accompanied by Directors of Sperry Gyroscope Ltd., Bracknell. The principal reason for their visit was to discuss the American Sperry Research Programme and the company's future activities.

Amhurst Thomson, S.P.S.O., has retired from ACO after a long, varied and distinguished career in Government service.

Educated at Radley before proceeding with a Bostock Exhibition to Christchurch, Oxford, he switched his university studies after one year from chemistry to physics, not wishing to be confined—as he put it—to one branch of the subject.

After graduation he spent 18 months with Vickers Armstrong, Crayford, gaining experience in " using tools "; proceeding next to Scophony Limited to do research into novel systems of mechanical/optical television.

He entered Government service as a member of a War Office research team at Bawdsey developing radar. When war broke out in 1939 he was precluded from active service as a result of an accident in his student days and remained with the radar project when it was transferred to Christchurch (Hants). Here he invented and developed a very accurate ranging system for coast defence radar.

Thomson now made what was perhaps his greatest contribution to the wartime allied cause when, in collaboration with W. A. S. Butement and E. S. Shire, he invented the proximity fuze. It was decided to apply the fuze first to the three-inch rocket and for this purpose he moved with a small team to the Rocket Establishment at Aberporth. In 1942 he returned to Christchurch to join a team under Professor C. D. Ellis working on gun applications of the fuze.

Meanwhile however, the Tizard Commission had visited the United States and, as one of the results of this visit, it was decided to rely on America for Army and Navy fuze supplies rather than continue British development.

The urgent requirement then became to apply the fuze to Naval anti-aircraft guns. There were five different types in the Fleet, each presenting a separate problem and the need arose for a liaison officer in the U.S. and trials facilities in the U.K. Thomson was transferred to DNO to act as liaison officer with Washington and to take charge of a small group at Bristol University, responsible for equipping a new gunnery range at Shoeburyness for proximity fuze trials. After a number of visits to the United States the V1 raids on Southern England shifted the emphasis to shells for Army A.A. guns, to which the fuzes were applied with some success.

Although Thomson had resolved to leave Government service at the end of the war, he was persuaded to stay on by R. W. Sutton, a Bristol University neighbour and old acquaintance, who had been running a larger group there from ASE developing valves. Infected by Sutton's enthusiasm, the two groups merged to found a new establishment for valve development. Thus SERL was born.

At SERL, Amhurst Thomson was the key figure in a series of successful projects. A 1940 invention of his, not taken up at the time, was demonstrated in 1949. This was " pulse compression " applied to radar which this time was adopted by RRE in Britain and in the U.S.A.

Among the honours accorded to him in this period were an ex gratia award (with Butement and Shire) for the invention of the proximity fuze and the United States Medal of Freedom for associated work in the U.S.A.

On being transferred to the Harlow SERL group in 1951 he undertook pre-production of microwave valves developed at the parent establishment at Baldock.

On his principle of having a quinquennial change of project, he turned his attention in 1954 to the application of ferrites to microwaves. This involved the first British development and manufacture of this class of material. An outcome of the work was the production of single crystal garnets and their introduction into microwave technology, giving substantial technical advantages.

Back in the Baldock establishment in 1962, the possibilities of the gas laser as a navigational instrument became his major preoccupation and he set up a group to develop a ring laser " coelostat " to demonstrate the capabilities of this device as a rotation detector.

The transfer of this work in 1968 to ACO, the H.Q. of navigational R & D, was a logical step and a fortunate one for the Establishment. Here Thomson continued his research into laser problems and shared his experience and knowledge in this field with colleagues who were to carry on with the work.

Although the period spent at ACO was a very small proportion of his service career, it was not an insignificant one. Amhurst Thomson won the respect and regard of all who had dealings with him, whether professional or social. In technical matters, his knowledge, experience and rapid grasp of a situation leading to a reasoned conclusion were a feature of discussions with him and seemed to operate in almost any discipline which became a topic, while on social and informal occasions his general knowledge, charm and courtesy were spiced with a lively sense of humour.

It was with difficulty that his diffidence was overcome and he was persuaded to attend a farewell gathering of his ACO colleagues and friends, when Mr. H. J. Elwertowski, Chief Scientist, presented on their behalf a cheque and an RNSS armorial plaque. Mr. Elwertowski's tribute was followed by a characteristically brief reply which could be described as the motion for the adjournment.

All Tommy's friends at ACO, together with those from SERL and throughout the RNSS, wish him and Mrs. Thomson good health and every happiness in their retirement.

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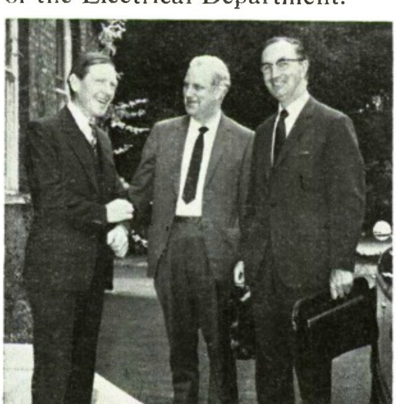
Admiralty Engineering Laboratory

Sir George G. Macfarlane, C.B., Controller Research; and Mr. B. W. Lythall, C.B., Chief Scientist, Royal Navy; paid a visit to the Laboratory on 29th July, 1971. The morning of the visit was devoted to a tour of the Mechanical Department and the afternoon to a tour of the Electrical Department.



Left to right; Capt. W. G. McC. Burn, R.N.
Mr. B. W. Lythal, C.B., C.S., R.N. and
Sir George Macfarlane, C.B. Controller Research.

Mr. E. R. C. Morrison was awarded the Imperial Service Medal on May 7th. The award was made by Capt. W. G. McC. Burn, R.N., the Superintendent of the Establishment. Mr. Morrison joined AEL in 1936 as a Laboratory Assistant, and worked in the Metallurgical Section for nearly 25 years. He became a Senior Scientific Assistant in 1947 and in 1959 transferred to the Noise Reduction Section. He has played an important part in the noise measuring activities of the Laboratory.

Mr. A. G. Hinchliffe who recently retired as a Chief Draughtsman and who served at AEL during the early 1950's was awarded the sum of four hundred pounds in recognition of his work in designing the AEL pipe joint for hydraulic systems.

Mr. R. E. Puxty, a former Chargeman of Skilled Labourers who retired through ill-health in 1970, was presented with the Imperial Service Medal on 25th June, 1971, by the Superintendent Captain W. G. McC. Burn, R.N.

His many friends and colleagues were deeply shocked to learn of the sudden death of **Mr. Frank H. Haywood** at his home on the night of 26th April, 1971. He was 63 years of age. After spending some years in the Electrical

Supply Industry after the completion of his training, he transferred to the teaching profession and became a full time lecturer at the Chesterfield Technical College. In 1943, he was directed to take up an appointment at the Admiralty Engineering Laboratory and entered as an Experimental Assistant, being promoted after a short period to Senior Experimental Assistant. During the re-organization following the war he became a Senior Development Assistant and then a Technical Class Grade B until the transfer of the Development Assistant Class to the Experimental Officer Class when he became a Senior Experimental Officer in 1958 and took charge of the Ships' Weapons Control Systems Section. Later he was transferred to Main Grade Engineer in the Royal Naval Engineering Service whilst continuing as Head of Section.

He was recognised throughout the Service as an outstanding authority on Fire Control Systems and computing elements. Amongst his wide and varied contributions he developed instrumentation for static and dynamic measurements in Fire Control Systems, including the Dynamic Tester for testing the MRS3 system (for which he received an award), and his Voltage Measuring Unit. The Drayton Submarine Positional Display was another recent development owing much to his earlier ideas and work.

At the time of his death he was shortly to undertake a visit to New York, U.S.A. as a representative of MOD(N) on problems of computing elements.

Mr. Haywood was completely dedicated to his work and an example to all those who worked for him. He was noted for his understanding disposition and respected by all his colleagues. No one asking his advice ever came away without having his problem reduced to manageable proportions. His knowledge in his chosen subject was profound and unique. With his death an era of development in Fire Control Systems closes, an era of such outstanding changes that it is unlikely ever to be repeated.

We offer our deepest sympathy to his widow and three sons.

The Admiralty Engineering Laboratory, in conjunction with the Fleet Air Arm, Navy and Army, put on an exhibition showing some aspects of the research and development work carried out in the establishment at the local Hillingdon Show held 26th and 27th June, 1971. A.E.L. contributed a total of seven display stands, and also carried out the electrical installation and lighting for the combined Services displays. Mr. Nugent, was responsible for the exhibition arrangements, seen by over 30,000 visitors during the two day show in spite of inclement weather.

The illustration shows the model of a Stalwart Troop Carrier made by Mr. Barry Joplin, standing nearest the model, whilst Mr. L. Drewett explains the modus operandi of the radio control link to two youthful visitors. In the background may be seen part of the Apprentice Training Stand giving details of the electrical and mechanical craft training at A.E.L. Examples of the apprentice work were shown, the standard of which was extremely high. One interesting electrical item was a digital clock designed and built by Mr. J. K. Aked, assisted by Mr. J. Reeves.

Although the main effort was provided by the Services Section of A.E.L., the Mechanical Department provided a display showing the Ships Stabilisation System designed and developed by the Machinery Control Section, demonstrated on an elegant model of a Leander class frigate constructed by Mr. L. Rookes, whilst the Electrical Department provided a stand showing the Deck Landing Projector Sight system developed by the Weapons Control Section. The display carried a detailed scale model of the Deck Landing Projector Sight equipment made entirely by Mr. E. C. Sims.

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Admiralty Experiment Works

On May 5th AEW was visited by the independent members of the Defence Scientific Advisory Council led by Professor Sir William Hawthorne and demonstrations were made in each facility. The members were impressed by the range of work carried out and the manner in which it was tackled.

In June a small AEW team plus Lieutenant Stuurman of the Royal Netherlands Navy conducted a "seakeeping" trial on the U.S. Navy hydrofoil boat *Tucumcari*. Unfortunately the weather was glassy calm and so the team carried out tests on the boat's propulsion and turning capabilities instead. This included crash stops from "flying high" at speeds in excess of 40 knots.

The Superintendent, Mr. A. J. Vosper, F.R.I.N.A., R.C.N.C., Chief Scientist Mr. J. Conolly, B.Sc., F.R.I.N.A., and Mr. B. O. Wall, B.Sc., Eng. A.C.G.I., M.R.I.N.A., R.C.N.C., visited Canada and the United States from June 2nd - 13th accompanied by Dr. J. Foxwell and Mr. J. Leaper to exchange information on ship hydrodynamics. Their visit proved fruitful and their return started a wave of new activity throughout the Establishment.

AEW was visited by the Controller of the Navy, Vice Admiral Sir Anthony Griffin, C.B. on July 27th and Controller of Research and Development Establishments and Research, Sir George Macfarlane, C.B., and Mr. B. W. Lythall, Chief Scientist (R.N.). on August 2nd. The full range of demonstrations was carried out on both occasions with the usual heart-stopping moments for the demonstrators. A typical example was that of the radio controlled free manoeuvring submarine model which failed to start when the visitors were present. A swift blow by the accompanying diver produced the desired result and was followed by a perfect demonstration.

AEW was pleased to welcome a U.S. Exchange Scientist Mr. R. Boswell on August 9th who is to work with us for a year, mainly on the subject of the prediction of rudder forces and torques. Mr. Boswell comes to us in exchange for Miss W. Bolton who has nearly finished her year at the Naval Ship Research and Development Centre in Washington. We hope that Bob will enjoy his stay with us.

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Admiralty Marine Engineering Establishment

On 27th July, the Controller of the Navy Vice Admiral Sir Anthony Griffin, K.C.B., and Captain J. S. Grove, RN, his Naval Assistant, accompanied by Mr. S. J. Palmer, Deputy Director General Ships, visited the Establishment. The Superintendent Captain B. V. W. Tyler, RN, and senior members of the RNSS Staff, Mr. P. W. Harrison and Dr. J. W. Hardcastle, welcomed the visitors and escorted them on a conducted tour of the Establishment's facilities.

On 2nd August, Sir George McFarlane, C.B., the Controller of Establishments and Research MOD, in company with Mr. B. W. Lythall, C.B., Chief Scientist Royal Navy, visited the Establishment in association with Sir George's recent appointment.

A team from the US Naval Ship Engineering Centres, Washington and Philadelphia has recently spent some time with the Central Boiler Inspection Unit to study RN methods of NDT Boiler durability assessment with the view to introducing similar techniques in the USN.

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Admiralty Research Laboratory

Harry Margary retired from the RNSS on June 30th, 1971 after 31 years' service, the last 24 of which were at the Admiralty Research Laboratory, Teddington.

A native of Hampshire, he graduated in 1934 from Gonville and Caius College, Cambridge, with a Mechanical Sciences Tripos, and trained as an electrical power engineer with Metropolitan Vickers. His admiralty career began in 1940, when he joined the Mine Design Department at H.M.S. *Vernon* as a TEO under Oliver Thorneycroft. His early work there was on the sweeping of acoustic mines; later he was concerned with the control of ahead-thrown anti-submarine weapons, and was associated with "Parsnip"; "Squid" and the Mark 10 AS mortar.

In January 1947 he joined ARL and, for 10 years applied his inventive genius to the solution of a wide variety of instrumentation problems. His work included instrumentation for air-dropped torpedo trials and for atmospheric ionisation measurements, and he was responsible for setting up a comprehensive sonar research station in Port Ballantrae, Northern Ireland.

From 1957 he became wholly concerned in active and passive sonar research, and for the last five years he has headed ARL's Sonar Research Group. Under him the group has made very significant advances in sonar science, and some direct contributions to the development of future fleet sonars. These successes were due in large measure to the strong group spirit engendered by his leadership. Harry Margary won the respect and support of all who worked with him, by his infectious enthusiasm, and his genuine interest in their problem, whether technical or personal.

Harry has never been half-hearted in anything he has undertaken, and this is true also of his private pursuits away from the laboratory, which are trout and salmon fishing, restoring and managing his "stately home", Lympne Castle, and the collection and reproduction of 18th century maps. His contributions in these last two fields won him recently the honour of election as a Fellow of the Society of Antiquaries, and it was his increasing involvement in these activities which persuaded him to his early retirement from the RNSS.

By his retirement ARL has lost a colourful and popular character. His popularity was much in evidence by the attendance at his farewell presentation, which was made by Dr. Lee, Director of ARL. The presentation was in a way a notional one, since the gift, subscribed by all his friends at ARL, is to be a map for his collection, and Harry's own expertise was called for in selecting it. Harry responded by presenting to ARL a framed sheet of one of his own map reproductions, showing the environs of Teddington in 1746.

In a further farewell gesture, which was so typical of them, Harry and his wife entertained some fifty of his ex-colleagues and their families for a memorable (and well fed!) afternoon at Lympne Castle. His many friends throughout the RNSS join with ARL in wishing him a long and happy retirement.

Admiralty Surface Weapons Establishment

The photograph shows the Establishment's Director, Mr. H. W. Pout (right), greeting Dr. L. J. L. Heureux (left) and Dr. W. Petrie, both of the Canadian Defence Research Board, on their recent visit to A.S.W.E.

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Mr. H. W. Pout, Director of ASWE, visited the United States in May, accompanied by Mr. I. A. McCord, Mr. P. R. Clynick, Mr. B. N. Amos, Mr. M. H. A. Smith and Commander J. B. Read. The aim of the visit was to discuss with the United States Naval authorities possible future developments in the concept of Automated Action Information Systems, and to exchange information on techniques for use in the development of such systems, in the integration of weapon systems and in the processing and presentation of data in AIO's. The team spent two days in presenting papers, outlining future concepts and in discussion at the Office of Naval Research in Washington. They subsequently visited the Naval Electronics Laboratory Centre at San Diego and the Naval Weapons Centre at China Lake to hear the U.S. ideas and to have further discussions and demonstrations of equipment. The visit resulted in a favourable response from the U.S. naval authorities on U.K. ideas for the future. Mr. J. R. C. Thomas represented the Navy at the meeting and also visited a number of American facilities concerned with radar developments. Later in his visit Mr. Thomas participated in another exchange project concerned with Action Information Organisations when he was accompanied by Commander J. B. Read of ASWE's ADA Rule-Writing Group and Commander I. E. Johnston of D.N.O.R.

Mr. W. D. Mallinson retired on July 30th, 1971 after nearly 32 years continuous service with the Admiralty. Before joining he had for the previous 11 years been working for Standard Telephones and Cables on establishing wireless stations at home and abroad.

Bill Mallinson started his Admiralty career when he joined the Signal School in Portsmouth as a Technical Officer in October 1939. In those days visual signalling was still quite important and his first task was to design a portable board to show visual signalling code changes. However, the new radiolocation systems were requiring more and more effect and he soon became responsible for the mechanical design of the first experimental 50 cms radar transmitter (of which over 100 were made from his design sketches).

After designing the Type 282 Display and its Yagi Aerials he was seconded to J. F. Coales' group at Onslow Road, Southsea to work on the design of gunnery radars. Here in the old condemned school that they occupied at Onslow Road they were subjected to the blast and shock of enemy attack and in September 1942 they were all evacuated to King Edward's School at Witley. Bill continued to work on gunnery radars which included the last of the manual tracking radars (Type 275) and the first of the auto-follow radars (Type 262). It was about then that the first naval guided weapon system, later to become known as SEASLUG, was conceived. Little did Bill know at that time that this brain child was to become one of his major pre-occupations.

One of Bill's talents is his ability to benefit by experience and to apply sound engineering commonsense to the design of naval equipment (even if sometimes it was at the expense of a dB or two!). This is clearly illustrated in an experience he had while attending H.M.S. *King George V*'s full speed trials in the First of Clyde. He was asked to climb up to the forward 275 director with an AVO to find out why the transmitter was not working. He found that finding the fault while holding on for dear life high above the deck and dizzy with the wind rammed up one's nostrils was not conducive to the easy maintenance of electronic equipment. This experience is one of the reasons why Type 901 is easy to maintain as among other things it has its transmitter and other RF equipment mounted in a nice cabin slung below the 901 aerials.

In September 1947 he became Project Leader for Type 901, the last major project to be designed and developed inside the establishment. His unobtrusive leadership and ability to draw difficult people together, welded a large number of men and women into a happy dedicated team. There were difficulties and frustrations at times, especially when SEASLUG missiles behaved in a rather erratic manner and one had to identify whether it was the radar or missile that was at fault! In July 1951 the Project Team moved from Witley to Lab Block 3 at Portsdown. 901 experimental and development models were fitted at Portsdown, Aberporth, Woomera and on H.M.S. *Girdle Ness*. He visited Aberporth on many occasions but to his great regret never managed to visit Woomera and return to the Australia he had visited in his STC days. However, Australia came to Lab Block 3 in the form of the strong Australian accent of the Australian team that was being trained to maintain and operate the 901 at Woomera! It was of interest to hear recently that the experimental 901 at Woomera is still going strong; a great tribute to Bill Mallinson and his team's good design work.

In January 1952 Bill Mallinson was promoted to SPSO and he became Head of GX Division. He now took such projects as 992/TIU3, SEACAT and the radar aspects of MDS1 and MRS3 under his wing. In 1958 the final development model of 901 (GMY 4) was fitted at Portsdown and the development culminated in the first ship-fitting of 901 in H.M.S. *Devonshire* in 1960. Much of the credit for the reliability and accuracy that the SEASLUG System has since demonstrated is due to his leadership and professional capability. His friendliness, cheerfulness and consideration for his staff was also demonstrated by those happy occasions of the GX and MGX Christmas parties, much enjoyed by all those who had the privilege of attending.

In 1965 he was appointed Acting Head of the Weapon Department and became an acting DCSO. After becoming a disestablished SSO at three-score years he helped with some of the supporting work on SEAWOLF. However his many years of active association with gunnery and missile radars came to an end in 1970 when he was put in charge of the planning and co-ordination of ASWE's Open Days.

This large ab-initio exercise was a new challenge and often a difficult battle with people to make them have constructive thoughts and to provide the necessary effort to achieve the aims of the Open Days. His personal qualities and drive however met this challenge and everything culminated in the very successful Open Days praised by all for its smooth organisation and its professional presentations.

Bill Mallinson will long be remembered and it is hoped that he will now find more time to enjoy his many varied outside interests, among which must be numbered old cars, music, good food and wine. He is also a very ardent supporter of the IEE and sometime ago was elected Chairman of the IEE Southern Centre.

As a token of the affection and respect in which his colleagues hold him the Director presented him with a Tandberg stereo tape recorder, a medallion, an RNSS crest and a cheque. In making the presentation the Director paid tribute to Mr. Mallinson's long and devoted service and wished him a long and happy retirement.

On May 31st, 1971 **H. W. (Binnie) Hayles** retired from the RNSS after 45 years continuous service to the crown, first as a serving member of the Navy, then as a civilian officer at ASWE.

Educated at Newport Grammar School, Isle of Wight and given the choice in 1926 of joining the Service or the ranks of the unemployed, he enlisted as a boy seaman and became a boy telegraphist. During the next 12 years he served, first in H.M.S. *Iron Duke*, Jellicoe's flagship at Jutland, in battleships in the Mediterranean and in the Home Fleet. A footballer of great promise he represented the Navy on various occasions, played as an amatuer for Southampton, toured South Africa with an Inter-Services Eleven during the 1935 Silver Jubilee celebrations and was deprived of an Amateur International Cap by Mussolini who chose to invade Abyssinia at an inopportune moment, requiring the return of Leading Telegraphist Hayles to Malta. In 1936 he was promoted Petty Officer and in 1938 made commissioned Warrant Officer.

During the 1939 - 1945 hostilities, he served in the Mediterranean, South East Asia and the Atlantic, first on board H.M.S. *Ramillies* during which time he took part in the raid on Taranto and carried out convoy escort duties in the Battle of the Atlantic. After a period of duty in Devonport preparing H.M.S. *Campbelltown* for the attack on the lock gates at St. Nazaire, he returned to the Mediterranean to set up the tactical communication links during the Torch landings at Algiers. Then followed the assaults on the beaches of Sicily and Salerno. After establishing the communication links for the Navy in Naples he returned to lecture in Leydene followed by another spell of lecturing in *Collingwood*. In this period he was promoted first to Lieutenant then Lt. Commander. After another spell of duty in the East Indies Station and the Persian Gulf he returned home to take up an appointment of Technical Applications Officer to Q Division in ASWE in 1952. On leaving the Navy in 1955, he remained in ASWE as an Experimental Officer in the Post Design Division. On the decision to implement the Nassau Agreement, he was transferred to the newly formed XCP Polaris Division as a member of the system engineering group for the communication systems in SSBns, a position which his experience and tact were well demonstrated. In 1966 he was promoted to SEO and, at the age of 60 in 1970, reverted to SSA to assist in completing the preparation of the exhibits and planning for the ASWE Open Days.

He retired on May 31st, 1971 and will begin his retirement as he intends to continue, by heading, complete with wife and caravan, for a three month " swan " round Europe.

He will, no doubt, now be able to indulge to the full his extra-mural activities of camping, fishing and stamp collecting.

Binnie Hayles will be greatly missed by his associates, colleagues and friends in ASWE, combining as he does a gift of tact; an ability to listen sympathetically to all points of view and the rare quality of instilling confidence by his manifest integrity.

His friends and colleagues at ASWE wish Binnie Hayles, and Mrs. Hayles, a very happy retirement and success in any of his undertakings.

Mr. Harold Winstock retired in August after 34 years of Admiralty service since he joined the Mine Design Department of the Admiralty at H.M.S. *Vernon*. He had taken his degree in engineering at Imperial College London, together with his ACGI, and had been working at the late lamented Handley Page. He started work on the design of very large magnetically-actuated submarine and surface-ship laid ground mines, one of them being popularly known as the " dust-bin." During the latter part of the war and immediate post-war period he worked on the design of components for aircraft-laid mines, including the then highly secret pressure-actuated mines. He then moved to the Research Division and for 10 years worked on shock-proofing and hydro-ballistic scale modelling of entry conditions of mines and depth-charges.

In March 1959 he joined ASWE under the Way Ahead re-organisation and worked with Mr. Tooley on the hydraulics of a gun-mounting. This was the first time during his Admiralty career that he worked on the subject he had specialised in while at Handley Page! When this section was broken up on Mr. Tooley's retirement Mr. Winstock joined the Shore Station Communications division, with a complete change of work on W/T stations at Bodmin and Mauritius.

In July 1965 he took up his present job as deputy head of the R. & D. Finance and Contracts section. Here he has been wise counsellor and occasional prod to almost every Project Leader. As a token of their respect and affection his colleagues presented him with some suitcases, a guide book and an RNSS crest. We wish him a long and happy retirement.

On July 28th, 1971, **Mr. A. R. Martin,** Senior Experimental Officer of the Installation Engineering Division at ASWE retired on medical grounds. Arthur Martin developed trouble with his eyes (detached retina) in March 1970, and during the period until his retirement he underwent a series of operations on both eyes. Arthur's present condition is such that he can now see reasonably well with one eye but the other shows little sign of improvement; however he is enjoying good health.

Arthur Martin spent 43 years in Government service having entered Portsmouth Dockyard as an Electrical Fitter apprentice in 1928. In 1936 he joined HM Signal School in RNB Portsmouth as a draughtsman in the Fitting-out Section of the drawing office. Following war damage to the Signal School building the Section moved to Commercial Chambers in Portsmouth and in 1941 to Lythe Hill House, Haslemere. On the formation of the RNSS in 1946 he was assimilated as an Experimental Officer and in 1966 was promoted to SEO.

During the war and early post war years Arthur Martin was concerned with the installation aspects of radar equipment and associated aerials. In 1952 ASWE moved to Portsdown and following a re-organisation of the Installation Division he was put in charge of the Ship Section for the Guided Missile Destroyers with responsibility for the installation development and engineering for communications, navaids and radar for these ships.

A private presentation has been arranged to give Arthur a cheque from his many colleagues and friends who wish him, and his wife Joyce, a long and happy retirement in their home, which Arthur himself designed, at Horndean, Portsmouth.

Ian McCord, S.P.S.O., Head of XRB Research Division, died in the Royal South Hants Hospital at Southampton on 1 July, 1971 at the very carly age of 48.

He joined the Establishment in 1951 at Witley after taking an Honours Degree in Electrical Engincering at Birmingham University. He was placed in the DX Division under Mr. D. Stewart Watson and beeame a member of the team developing the Comprehensive Display System. He quickly established himsclf with the development of eleetronic symbol writing on cathode ray tube displays and his CRT Cloek whieh graphieally showed off the application of this work, was widely demonstrated. Later he was appointed the UK Project Leader for the Canada-UK-US TIDE digital data link, which is for intercommunication between eomputer fitted ships, and then still responsible for TIDE took a leading part under Dr. Benjamin in the research phase of the Aetion Data Automation (ADA) system. When it entered full developmcnt Ian became Project Leader for the ADA system for the second batch of the County Class Guided Weapons Destroyers. This was the first of the multi-purpose ADA systems concerned with the eo-ordination of most of the ships' weapons, and the new problems whieh he and his team had to overcome would have more than daunted most other people. The hours worked by him and his team at ASWE and in H.M.S. *Fife* and H.M.S. *Glamorgan* added up to an enormous total. His junior staff would do anything he requested, as he never asked anyone to do anything he couldn't do himself. He was always ready to take off his jacket—and he frequently did to get people out of any kind of trouble.

He was rewarded by promotion to SPSO in 1969 and given charge of the XRB Research Division to whieh post he brought his now familiar enthusiastie drive and originalty of mind in taekling problcms quite new to him. However, he then characteristically set about preparing a thesis for a Ph.D. to Birmingham University; it was well advanced and his spirit was such that he had in fact been working upon it in hospital until not long before his passing.

Outside these considerable efforts at ASWE his energy reached cven higher limits in his private life. He very successfully designed and built his own house entirely with his own hands, without benefit of architect or buildcr, on a small holding on which he kcpt horses and other animals.

But still he had energy to spare and he acted in, produced and stage-managed plays not only for the ASWE Theatrieal Society but for his loeal Wiekham Players as well. He served as Chairman of the ASWE Theatrieal Society Committee and at the time of his death was Acting Treasurer. In addition for several years now he has taken part in a presentation at the Britannia Royal Naval College, Dartmouth which included his acting in a playlet illustrating the importance of all RN Officers understanding the roles and teehnical work of the R & D etablishments.

Another example of his energy and drive was his successful defence of himself—widely reported in national newspapers—when he was eharged with exeeeding the speed limit as shown by a police radar speed trap. He knew that he had not exeeeded the limit and he made time to go to great lengths and expense to produce clear cvidencc in court which showed the eonditions under whieh a doppler CW radar could produce a false rcading.

He was a man of great compassion to animals as well as to humans. Some few years ago, after one of his horses had broken a leg and been condemned by professional opinion, Ian refused to accept the vet's verdict and, with the help of mechanical engineer Guthrie Easton, lately of ASWE, designed and made a unique tackle which immobilised the animal's limb and allowed an eventual eomplete reeovery.

Ian will be aeutely missed, not only at ASWE and by the RN but by the many friends which he made throughout the NATO Navies and, partieularly, the USN. We shall all cherish our own memories of a staunch colleague and a most remarkable man.

Mr. K. V. Watt has been nominated to attend the Senior Officer's War Course at the Royal Naval College, Greenwich. Mr. Watt's nomination has been accepted and he will be away from the Establishment for five months with effect from mid-September.

Mr. R. S. Dunn, formerly of AUWE. has been appointed Officer-in-Charge of the Experimental Department of H.M.S. *Excellent* in place of Mr. J. E. James who retired at the end of May.

The Establishment held its first Open Days during the week beginning June 28th. Practically all of ASWE's activities were covered, the large number of exhibits ranging from such things as working demonstrations of an experimental long-range 3-D radar and satellite communication terminals to computer rule-writing, environmental testing and ring lasers. Over 12,000 people visited the Establishment during its Open Days week. (A fuller report appears as a separate article in this issue of the Journal).

Mr. J. Alvey visited Australia in May to discuss the range facilities at Woomera and to have discussions with Australian naval and scientific personnel. In the brief time that he was there, Adelaide had half its annual rainfall and it even rained in the desert of Woomera.

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Admiralty Underwater Weapons Establishment

The annual cocktail party given by members of the Principal Officers Mess was held at AUWE Southwell on Friday, 18th June. An extremely pleasant occasion, the party was attended by almost 300 members and guests.

The periodic meeting between Director General Weapons (Naval) and Flag Officer Submarines, accompanied by their staffs, took place at AUWE(N) on 17th June. On the following day a meeting between the Controller and Director General Weapons followed, also at AUWE (North)—after lunch both Admirals went for a short trip in the visiting U.S. Navy hydrofoil *Tucumcari*, and had discussions with the American officers in the mother ship U.S.S. *Woods County*.

A torpedo assessment case-study was presented by A. E. Williams to the Military Operational Analysis course at the Royal Military College of Science, Shrivenham on 26th May.

Mr. F. S. Burt, Deputy Director Weapons Research and Development (Underwater) accompanied by Captain J. S. Launders, D.S.O., D.S.C., R.N., Director Weapons Equipment Underwater and Commander K. D. Vicary, M.B.E., R.N., made a two week visit to the United States in June for the purpose of visiting laboratories and establishments engaged upon ASW work and to attend the 18th Meeting of Sub-Group ' G " TTCP of which Mr. Burt is the U.K. National Leader.

Presentations and briefings on ASW matters at the Pentagon and at the Naval Undersea Systems Centre at Newport Rhode Island and New London, Connecticut occupied the first week.

San Diego, California was the venue for the Sub Group " G " Meeting at which some 25 Australian, Canadian, New Zealand, United Kingdom and United States scientists and service personnel were present. Discussions and briefings were held at the Naval Undersea Research and Development Centre, who also acted as hosts.

The AUWE Exhibition was once again one of the highlights of Portland Open Days on 24th and 25th July, when over 30,000 members of the public mostly holiday-makers who rarely meet the Navy, thoroughly enjoyed the occasion. Great interest was shown in the exhibits, and some novel explanations given by mothers to small children were overheard.

Two representatives from AUWE, Mr. P. Redgment and Mr. R. J. Halcrow went to sea in the U.S.N. Hydrofoil craft *Tucumcari* during its recent visit to Portland. The purpose of the visit was to consider the potential value of the craft for A/S warfare. The stability of the craft at high speed and the smoothness of the transition from hull mode to foil mode were noteworthy features. The craft is automatically banked during speed turns so that the apparent "g" force is maintained normal to the deck.

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Central Dockyard Laboratory

Mr. D. L. Griffiths (Superintending Scientist) visited U.S.A. from April 13th to May 7th, 1971. The main purpose of his visit was to attend the meeting of the TTCP sub-group P Working Panel P3 (Organic Materials) of which Mr. Griffiths is Chairman and U.K. national leader. The main topic of the meeting was the application of composite materials to military uses. While in the U.S., he took the opportunity to visit a number of firms and laboratories to discuss matters of interest both in connection with this topic and with materials programmes and problems in the naval field.

The eighth Plenary Session of the Permanent International Committe for Research on the Preservation of Materials in the Marine Environment was held in the Guildhall, Portsmouth, from May 11th to 14th, 1971. The Central Dockyard Laboratory were joint hosts with the Portsmouth Polytechnic. The Session was opened by the Flag Officer Spithead, Rear Admiral P. G. La Niece, C.B.E., and Mr. D. L. Griffiths, Superintending Scientist, was also present. The meetings were attended by Mr. D. R. Houghton who is one of the two Vice-Chairmen of the Group as well as Chairman of the Group on Biology and by Mr. J. Smith who has taken over from Dr. E. N. Dodd, as representative on the Marine Coatings Group.

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Directorate Co-ordinated Valve Development

Dr. C. S. Whitehead has joined DCVD from SERL replacing Mr. R. J. Sherwell who has been appointed to ASWE. Mr. N. H. Rock, Sc.Ad.(CVD) at BDS, Washington, is being relieved this month by Dr. Roger Allen of SERL on completion of his tour of duty. Mr. J. Firkins of SERL has joined DCVD, taking the place of Mr. R. D. Preece who has been recalled to SERL. Mr. A. D. Eraut has joined DCVD from SVTL, replacing Cdr. J. H. Gretton who has retired. Dr. M. O. Bryant and Mr. R. J. Sherwell visited government and industrial organisations in the U.S. in April 1971 to assess the present state of research and development of solid state microwave transmitting devices.

A meeting of the Anglo-French Working Group on Valves and Semiconductors was held in France in June 1971. It was attended, among others, by Mr. C. P. Lea-Wilson (U.K. Chairman), Dr. M. O. Bryant, and Mr. M. Hillier (U.K. Secretary).

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Naval Aircraft Materials Laboratory

Mr. R. C. Clark attended the 1971 Meeting of the NATO Aviation Fuels, Lubricants and Associated Products Working Party in Brussels. This was attended by delegates from all NATO nations with the exception of Greece, Luxembourg, Portugal and Turkey. A wide range of topics was covered and revisions made to the relevant STANAGS where necessary.

Over 2,000 square feet of laboratory space has recently been added to NAML to house the engine health monitoring section. This extension provides excellent facilities for the operational programmes of spectrometric oil analysis (see issue *J.R.N.S.S.*, Vol. 25. No. 6, dated November 1970) and lubrication system debris analysis, together with evaluations and investigations of new techniques of engine health monitoring for service with the Fleet Air Arm.

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Naval Construction Research Establishment

Professor H. Bondi and Mr. N. Hancock, Director Warship Design visited NCRE on June 21st, 1971. The work of the Establishment was outlined in some detail by the senior members of staff. This was followed by a short tour of the Establishment at St. Leonard's and the South Arm.

Vice Admiral R. G. Raper, C.B. and Vice Admiral Sir A. Griffin, K.C.B. visited NCRE on July 6th, 1971. They discussed various aspects of the work of NCRE with Mr. K. G. Evans, Superintendent and Mr. I. Campbell, Chief Scientist.

Sir George MacFarlane, Controller Research and Mr. B. Lythall, Chief Scientist R.N. visited NCRE on July 19th, 1971. Various aspects of the work of the Establishment were outlined by the senior staff before the party accompanied by Mr. K. G. Evans, Superintendent and Mr. I. Campbell, Chief Scientist toured the laboratories at St. Leonard's and the South Arm Site.

Mr. P. B. Wishart attended the NATO mine warfare working party, Navy study J/56 meeting at Kiel, Germany May 25th to 27th, 1971 and the meeting at the NATO naval Armament Group IEG6 sub group 3 at La Spezia, Italy, June 3rd - 4th, 1971.

Mr. W. D. Hart attended the 14th Meeting of TTCP Panel N2 held at AWRE, Foulness, May 17th - 20th, 1971. The following U.S. members of Panel N2 visited NCRE on May 24th, 1971: Mr. J. Kelso, DASA, Major W. Shepard, DASA, Mr. J. Masgasor, BRL, Mr. C. Kingery, BAL, Mr. J. Petes, NOL.

In co-operating with the Institute of Geological Sciences NCRE has provided the use of their instrumentation vessel B.D.V. *Barfoot* and their explosives officer Mr. C. C. Moore, O.B.E. in order to allow IGS to carry out underwater firings in connection with their seismological work.

The first test consisted of 50 300 lb. charges fired at various locations from the Shetland Isles to the Irish Sea in the period October 26th to November 13th, 1970 and the second a single shot of 10 tons fired in the North Sea on July 20th, 1971.

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Royal Naval Physiological Laboratory

The Superintendent, Dr. H. V. Hempleman, Dr. P. B. Bennett, Dr. J. Miller, and Surg. Cdr. E. E. P. Barnard, RN attended the XXV Congress of Physiological Sciences Satellite Symposium " Recent Progress in Fundamental Physiology of Diving " at Marseille 23rd and 24th July, at which Dr. Bennett presented the paper " Changes in the EEG during exposure to inert gas at high pressure." During the meeting the new French, ten man submersible, *Agyronete*, with diver lock-out capability to almost 2000 ft., was demonstrated by Commandant Cousteau together with its new ancillary facilities and buildings. Whilst Dr. Miller proceeded to Munich to the main meeting of the Congress, Dr. Hempleman, Dr. Bennett and Surg. Cdr. Barnard visited the COMEX diving facilities.

Dr. D. Burgess, S.S.O., has joined the Laboratory recently. He was formerly a graduate student at the University of Michigan under Professor J. Bean, an internationally acknowledged authority on the toxicity of raised pressures of oxygen.

Dr. B. Hills, Associate Professor of Surgery, Duke University, North Carolina, is at the RNPL during the summer as a visiting consultant. He will be working with members of the staff engaged on the respiratory problems of diving and related areas of underwater physiology.

Mr. J. Eaton was an advisory member of a trials team sent to H.M.S. *Angelo*, Malta GC between 20th - 30th August, to install and validate an air purification system for improving the habitability of their decompression facility. Mr. D. Stewart-Watson (Deputy Chief Scientist, Navy) and Dr. J. Tunstead (Director Naval Physical Research) visited RNPL on 19th August, to meet the staff and discuss their work.

Surg. Lt. D. Leitch, RN, is leaving the Laboratory for the Institute of Aviation Medicine, Farnborough on 4th October. He will be replaced by Surg. Lt. Cdr. R. Hanson, RN who is presently at IAM, Farnborough.

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Exocet Missile Agreement

In the Supplementary Statement on Defence Policy 1970 (Cmnd 4521) it was stated that subject to satisfactory conclusion of negotiations with the French government, it was intended that the EXOCET missile system should be widely fitted in surface ships of the Royal Navy during the 1970s.

After several months of negotiations, agreement has been reached on the terms of a contract for procurement of the EXOCET system and on a government to government Memorandum of Understanding, which will underwrite the contract terms. These, together, represent a satisfactory agreement to Her Majesty's Government. Decisions have therefore been taken to purchase EXOCET ship systems for wide fitting in frigates and larger ships, with a sufficient number of missiles to provide them with a surface to surface capability well into the 1980s.

On Saturday 5 June 1971 at the Air Show at Le Bourget an inter-Government Agreement relating to the EXOCET weapon system was signed by M. Debre, Secretary of State for National Defence, and Mr. Soames the British Ambassador in Paris. At the same time a contract for the suply of EXOCET missiles and associated equipment for the Royal Navy was signed by the British Government and SNIAS, who develop the EXOCET system.

These agreements provide for participation by British industry in the series production of the system, and mark an important stage in Anglo-French co-operation in the armament field.

Introduction of Title "Port Admiral"

Flag Officers of the Royal Navy who have previously borne the title "Admiral Superintendent" at the Royal Dockyards, will be re-styled "Port Admiral" with effect from September 15th.

New full titles of officers affected by this change will be:

Flag Officer Plymouth and Port Admiral Devonport

Flag Officer Medway and Port Admiral Chatham

Flag Officer Spithead and Port Admiral Portsmouth

Flag Officer and Port Admiral Gibraltar

Port Admiral Rosyth

The change reflects developments in the organisation and management of the various support facilities at the main bases. On the one hand, the responsibilities of General Managers of dockyards and of Principal Supply the Transport Officers have increased; on the other, a wider "naval base" concept has developed under which the Port Admiral is required to control and co-ordinate a wide range of base support activities. These include the ship repair and fleet maintenance organisations, stores and transport establishments, operational support elements and accommodation and other services for uniformed personnel.

The change in title is consistent with recommendations made in the Second Report of the Committee on Government Industrial Establishments under Sir John Mallabar that the title Admiral Superintendent should be eliminated.

Rockall Landing from R.F.A. Ship

The first geological map of Rockall can be produced as a result of a survey undertaken by scientists from the Institute of Geological Sciences. They were landed on the rock by helicopter from the Royal Fleet Auxiliary *Engadine* (Master: Captain E. D. J. Evans) which returned to Portland in the middle of June.

During the work on Rockall, a party of Royal Engineers prepared a site on which at a later date the Department of Trade and Industry hope to fix a navigational light for the assistance of shipping and fishermen. The *Engadine* is manned by personnel of the R.F.A. service but also carries a small R.N. team for controlling helicopter flying operations and the maintenance of the aircraft.

First Type 42 Destroyer Launched

H.M.S. *Sheffield*, the Royal Navy's first Type 42 destroyer, was launched by Her Majesty the Queen on June 10 at the Barrow-in-Furness shipyard of Messrs. Vickers Ltd. Her Majesty was accompanied by His Royal Highness the Duke of Edinburgh.

With a standard displacement of about 3,500 tons, *Sheffield* will be powered with all gas turbine propulsion systems comprising Rolls Royce engines—Olympus to meet full power demands and Tyne for cruising. The propulsion gearing is being supplied by David Brown Gear Industries. In addition to the Seadart surface-to-air (with a surface-to-surface capability) missile system, the *Sheffield* will be armed with the new automatic 4·5 in. Mk. 8 gun, and be equipped with a twin engined WG13 *Lynx* anti-submarine helicopter.

She has an overall length of 410ft. and a beam measurement of 47ft. and has high standard living accommodation with bunk sleeping and centralised messing, she will be air conditioned throughout the accommodation, office and operational spaces and represents a major step forward in the re-equipment of the Royal Navy.

The last ship to bear the name *Sheffield* was the 9,100 tons cruiser built by Vickers-Armstrong Ltd. at Newcastle-on-Tyne in 1936. During World War II, she took part in operations leading to the sinking of the *Bismarck* in May, 1941 and with other Home Fleet ships assisted in the sinking of the German battleship *Scharnhorst*. She was scrapped in 1967 after six years in reserve.

Immediately after the launch of the *Sheffield*, a section of the Type 42 destroyer which is being built by the company for the Argentine Navy was placed in the vacant berth.

Fourth Type 42 Destroyer Ordered

Lord Balniel, the Minister of State for Defence, announced on 10 June that a further Type 42 destroyer had been ordered from Vickers Ltd., Barrow-in-Furness. This is the fourth ship of this class to be ordered. The announcement was made at the luncheon after the launching of H.M.S. *Sheffield*, the first ship of the class, also built at Vickers, Barrow.

Two other ships of this class were ordered some two weeks ago from Cammell Lairds, Birkenhead.

BOOK REVIEW

The Teaching of Mathematics: Essays by A. Ya. Khinchin. Edited by B. V. Gnedenko. English Universities Press Ltd. Pp. 167 + xx. Price 55s.

Khinchin as well as being a world renowned mathematician was also extremely interested in the teaching of mathematics. In particular he thought that Russian teaching of mathematics just before the war was dominated more by the mathematical outlook of the 17th century than of the great logical axiomatic developments of the late 19th century. From 1939 until his death he was a persistent writer on the teaching of mathematics and his essays in this field were collected and published in book form under the editorship of his pupil Gnedenko in 1963. The book under review is a translation of a selection of these " Pedagogical Essays " published between 1939 and 1948 with one long essay first published apparently in 1961. As well as these essays which cover some hundred pages of the book there are two appendices, one giving a biography of Khinchin and one by Dr. Vere-Jones giving a survey of the school system in the U.S.S.R. This second appendix is interesting for its description of the organisation of Soviet schools, details of curricula (mathematics is compulsory), and even examples of examination papers.

The main aim of the book is to present the views of an eminent mathematician on the teaching of his subject. Khinchin appears to have had one principle for the teaching of mathematics in mind: That modern concepts should always, as far as possible, be used but when too difficult for the age of the pupil simplication must be such that it is neither vague nor impossible to be constructively modified in future rather than have to be completely abandoned. Too many English students of the early thirties were told to forget all the mathematics they had learned at school on first entering university. Paradoxically most found the advice singularly misleading.

Khinchin demonstrates the type of simplication possible for a number of concepts in a series of discussions. In this way he treats the difficult topics of the concepts of number, limits, and functional relationships and the clarity and rigour of his approach is persuasive. Under functional relationships he also discusses how the concepts of inverse functions and multivalued functions can be introduced. These essays were first written just before World War II.

There is a section written around 1941 about what definitions of mathematical quantities should be introduced in schools. This section ranges over a wide field and is mainly concerned with the principles behind axiomatics. The main theme is what concepts should be defined and what should be left undefined and in the latter case what " explanation " should be given. Khinchin makes the point that formal definition and description based on the real world are not necessarily incompatible. There is also a section on formalism and its abuse.

The last of Khinchin's essays is concerned with the benefits of a course in mathematics on the general education of man in a real world. There may be here an anology with the arguments that were once used for the teaching Latin in Grammar Schools and the essay is somewhat more philosophical than the rest of the essays in the book. In this chapter an attempt is made to show the importance of mathematical training for the conduction of many of the functions of living; accurate thinking, avoiding false generalisations, avoiding false analogies, finding general and not singular solutions, establishing a basis for complete and consistent classifications, and for providing a basis for such moral qualities as honesty, truthfulness, and even patriotism.

This is a fascinating book and should be of interest to anybody concerned with the mathematical education of the young. While there may be undisclosed " axioms " on the lack of individuality amongst pupils and teachers and even of the pupil's needs for mathematics in Khinchin's writings (probably not only confined to him) the book is valuable for its detailed discussion of the ways to introduce various mathematical concepts to pupils. The book is also valuable as a glimpse of what another country is doing about the teaching of mathematics in schools.

R. A. M. Bound

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